



*Volume 3 Issue 1*  
*February 2001*

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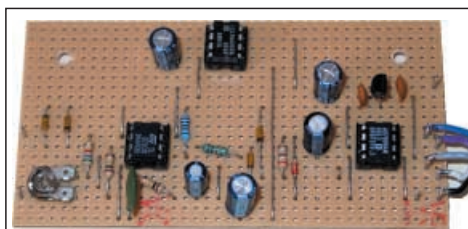
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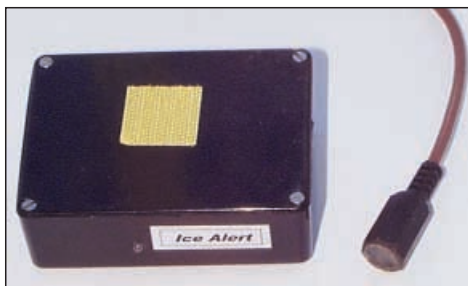
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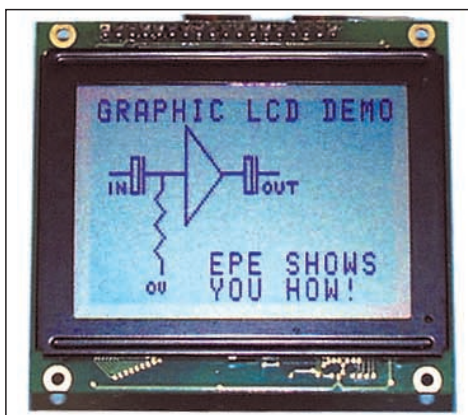
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## Free 16-Page Supplement

- HOW TO USE GRAPHICS L.C.D.S WITH PICS** by John Becker **Between 116 and 117**  
 A step-by-step guide to understanding and using pixel-matrixed graphics liquid crystal displays with your PIC microcontroller projects



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Our March 2001 issue will be published on Thursday, 8 February 2001. See page 83 for details

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# NEXT MONTH

## DIY LIGHTNING

*Short of divine intervention, most of us are never going to get to control nature's most spectacular effect. However, thanks to the genius of a 144-year-old physicist, you can.*

*The purpose of this article is to allow you, the reader, to build a working Tesla coil (see photo) with an arc output of at least 50cm, giving you a general idea as to why and how it works and a few ideas for some of the fun effects that can be demonstrated with it. But, be warned, the output from this project is easily capable of killing you if not treated with due respect.*

## DOORBELL EXTENDER

*This "through the mains" unit will extend your doorbell so you can hear it in the garage or workshop. It will also act as a control system to switch on or off a remote appliance from the comfort of your armchair, or as a safety button for the bed-ridden etc.*

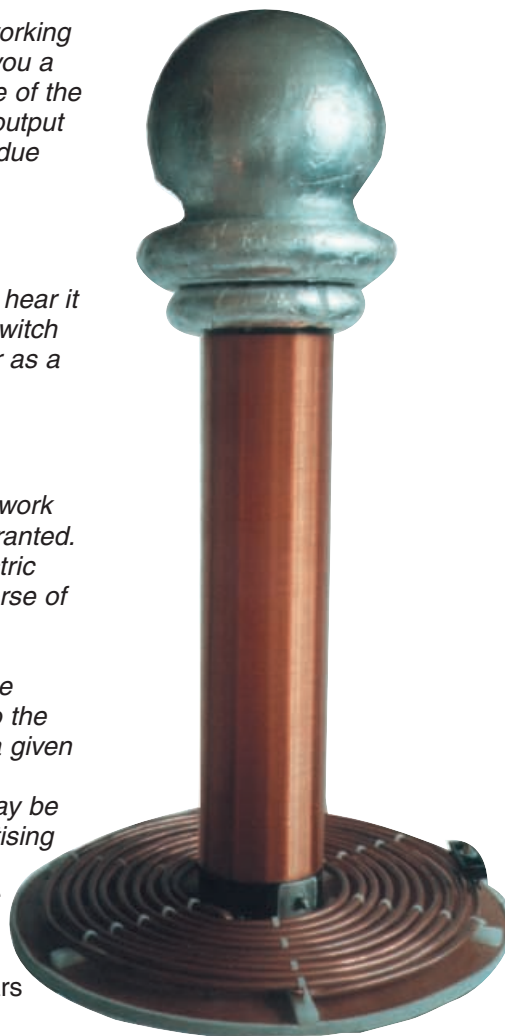
## BODY DETECTOR

*Capacitance is an extraordinary phenomenon, in that it is able to work through empty space. This is a quality that is normally taken for granted. The accumulation of charge on a metal plate gives rise to an electric field, which will affect another plate in direct proportion to the inverse of its distance. Capacitance, also, is one of a vast range of physical phenomena that may be translated into electrical oscillations.*

*The Body Detector featured in this article relies on the fact that the human body itself possesses a fairly large order of capacitance to the ground, and that if such a body approaches the positive plate of a given capacitor, its value will rise.*

*Due to its high sensitivity and good stability, the Body Detector may be attached to a wide variety of metal objects – in the process sensitising the entire object concerned.*

*Although in theory the Body Detector is dependent on the electric field which surrounds the human body, in effect it acts as though an invisible field were created around the object concerned – similar to the "invisible" defence shields seen in the latest Star Wars movie.*



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## PROJECT KITS

Our electronic kits are supplied complete with all components, high quality PCBs (NOT cheap Tripad strip board!) and detailed assembly/operating instructions

- **2 x 25W CAR BOOSTER AMPLIFIER** Connects to output of an existing car stereo cassette player, CD player or radio. Heatsinks provided. PCB 76x55mm. **1046KTT £27.95**
- **3-CHANNEL WIRELESS LIGHT MODULATOR** No electrical connection with amplifier. Light modulation achieved via a sensitive electret microphone. Separate sensitive control per channel. Power handling 400W/channel. PCB 54x112mm. Mains powered. Box provided. **6014KTT £27.95**
- **12 RUNNING LIGHT EFFECT** Exciting 12 LED light effect ideal for parties, discos, shop-windows & eye-catching signs. PCB design allows replacement of LEDs with 220V bulbs by inserting 3 TRIACS. Adjustable rotation speed & direction. PCB 54x112mm. **1026KTT £17.95; BOX (for mains operation) 2026XB £10.00**
- **DISCO STROBE LIGHT** Probably the most exciting of all light effects. Very bright strobe tube. Adjustable strobe frequency: 1-60Hz. Mains powered. PCB: 60x68mm. Box provided. **6037KTT £31.95**

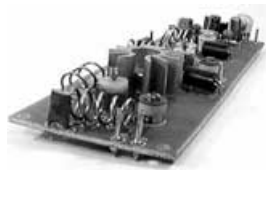
- **ANIMAL SOUNDS** Cat, dog, chicken & cow. Ideal for kids farmyard toys & schools. **SG10M £6.95**
- **3 1/2 DIGIT LED PANEL METER** Use for basic voltage/current displays or customise to measure temperature, light, weight, movement, sound levels, etc. with appropriate sensors (not supplied). Various input circuit designs provided. **3061KTT £13.95**
- **IR REMOTE TOGGLE SWITCH** Use any TV/VCR remote control unit to switch onboard 12V/1A relay on/off. **3058KTT £10.95**
- **SPEED CONTROLLER** for any common DC motor up to 100V/5A. Pulse width modulation gives maximum torque at all speeds. 5-15VDC. Box provided. **3067KTT £12.95**
- **3 x 8 CHANNEL IR RELAY BOARD** Control eight 12V/1A relays by Infra Red (IR) remote control over a 20m range in sunlight. 8 relays turn on only, the other 2 toggle on/off. 3 operation ranges determined by jumpers. Transmitter case & all components provided. Receiver PCB 76x89mm. **3072KTT £52.95**

## PRODUCT FEATURE

### 4 WATT FM TRANSMITTER

Small but powerful 4 Watt 88-108MHz FM transmitter with an audio preamplifier stage and 3 RF stages. Accepts a wide variety of input sources – the electret microphone supplied, a tape player or for more professional results, a separate audio mixer (like our 3-Input Mono Mixer kit 1052). Can be used with an open dipole or ground plane antenna. Supply: 12-15V DC/0-5A. PCB: 45 x 145mm.

**ORDERING INFO:** Kit 1028KT £24.95.  
**OPTIONAL EXTRAS:** 3-Input Mono Mixer Kit 1052KT £17.95. AS1028 £39.95.



- **SOUND EFFECTS GENERATOR** Easy to build. Create an almost infinite variety of interesting/unusual sound effects from birds chirping to sirens. 9VDC. PCB 54x85mm. **1045KTT £9.95**
- **ROBOT VOICE EFFECT** Make your voice sound similar to a robot or Darlek. Great fun for discos, school plays, theatre productions, radio stations & playing jokes on your friends when answering the phone! PCB 42x71mm. **1131KT £9.95**
- **AUDIO TO LIGHT MODULATOR** Controls intensity of one or more lights in response to an audio input. Safe, modern opto-coupler design. Mains voltage experience required. **3012KTT £8.95**
- **MUSIC BOX** Activated by light. Plays 8 Christmas songs and 5 other tunes. **3104KTT £7.95**
- **20 SECOND VOICE RECORDER** Uses non-volatile memory - no battery backup needed. Records/replay messages over & over. Playback as required to greet customers etc. Volume control & built-in mic. 6VDC. PCB 50x73mm. **3131KTT £12.95**
- **TRAIN SOUNDS** 4 selectable sounds: whistle blowing, level crossing bell, 'clackety-clack' & 4 in sequence. **SG01M £6.95**

- **PC CONTROLLED RELAY BOARD** Convert any 286 upward PC into a dedicated automatic controller to independently turn on/off up to eight lights, motors & other devices around the home, office, laboratory or factory using 8 240VAC/12A onboard relays. DOS utilities, sample test program, full-featured Windows utility & all components (except cable) provided. 12VDC. PCB 70x200mm. **3074KTT £31.95**
- **2 CHANNEL UHF RELAY SWITCH** Contains the same transmitter/receiver pair as 30A15 below plus the components and PCB to control two 240VAC/10A relays (also supplied). Ultra bright LEDs used to indicate relay status. **3082KTT £27.95**
- **TRANSMITTER RECEIVER PAIR** 2-button keyboard style 300-375MHz Tx with 30m range. Receiver encoder module with matched decoder IC. Components must be built into a circuit like kit 3082 above. **30A15 £14.95**
- **PC DATA ACQUISITION/CONTROL UNIT** Use your PC to monitor physical variables (e.g. pressure, temperature, light, weight, switch state, movement, relays, etc.), process the information & use results to control physical devices like motors, sirens, relays, servo & stepper motors. Inputs: 16 digital & 11 analogue. Outputs: 8 digital & 1 analogue. Plastic case with printed front/rear panels, software utilities, programming examples & all components (except sensors & cable) provided. 12VDC. **3093KTT £29.95**
- **PIC 16C71 FOUR SERVO MOTOR DRIVER** Simultaneously control up to 4 servo motors. Software & all components (except servos/control pots) supplied. 5VDC. PCB 50x70mm. **3102KTT £15.95**
- **PC SERIAL PORT ISOLATED I/O BOARD** Provides eight 240VAC/10A relay outputs & 4 optically isolated inputs. Designed for use in various control & sensing applications e.g. load switching, external switch input sensing, contact closure & external voltage sensing. Controlled via serial port & a terminal emulator program (built into Windows). Can be used with ANY computer/operating system. Plastic case with printed front/rear panels & all components (except cable) provided. **3108KTT £54.95**
- **UNIPOLAR STEPPER MOTOR DRIVER** for any 5/6/8 lead motor. Fast/slow & single step rates. Direction control & on/off switch. Wave, 2-phase & half-wave step modes. 4 LED indicators. PCB 50x65mm. **3109KTT £14.95**
- **PC CONTROLLED STEPPER MOTOR DRIVER** Control two unipolar stepper motors (3A max. each) via PC printer port. Wave, 2-phase & half-wave step modes. Software accepts 4 digital inputs from external switches & will single step motors. PCB fits in D-shell case provided. **3113KTT £17.95**
- **12-BIT PC DATA ACQUISITION/CONTROL UNIT** Similar to kit 3093 above but uses a 12 bit Analogue-to-Digital Converter (ADC) with internal analogue multiplexer. Reads 8 single ended channels or 4 differential inputs or a mixture of both. Analogue inputs read 0-4V. Four TTL/CMOS compatible digital input/outputs. ADC conversion time <10µs. Software (C, QB & Win), extended D shell case & all components (except sensors & cable) provided. **3118KTT £52.95**

## X FACTOR PUBLICATIONS

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Full details of all X-FACTOR PUBLICATIONS can be found in our catalogue. N.B. Minimum order charge for reports and plans is £5.00 PLUS normal P&P.

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- **TELEPHONE BUG PLANS** Build your own micro-beetle telephone bug. Suitable for any phone. Transmits over 250 metres - more with good receiver. Made from easy to obtain, cheap components. **R006 £2.50**
- **LOCKS** - How they work and how to pick them. This fact filled report will teach you more about locks and the art of lock picking than many books we have seen at 4 times the price. Packed with information and illustrations. **R008 £3.50**
- **RADIO & TV JOKER PLANS** We show you how to build three different circuits for disrupting TV picture and sound plus FM radio! May upset your neighbours & the authorities!! DISCRETION REQUIRED. **R017 £3.50**
- **INFINITY TRANSMITTER PLANS** Complete plans for building the famous Infinity Transmitter. Once installed on the target phone, device acts like a room bug. Just call the target phone & activate the unit to hear all room sounds. Great for home/office security! **R019 £3.50**
- **THE ETHER BOX CALL INTERCEPTOR PLANS** Grabs telephone calls out of thin air! No need to wire-in a phone bug. Simply place this device near the phone lines to hear the conversations taking place! **R025 £3.00**
- **CASH CREATOR BUSINESS REPORTS** Need ideas for making some cash? Well this could be just what you need! You get 40 reports (approx. 800 pages) on floppy disk that give you information on setting up different businesses. You also get valuable reproduction and duplication rights so that you can sell the manuals as you like. **R030 £7.50**

# SURVEILLANCE

High performance surveillance bugs. Room transmitters supplied with sensitive electret microphone & battery holder/cip. All transmitters can be received on an ordinary VHF-FM radio between 88-108MHz. Available in Kit Form (KT) or Assembled & Tested (AS).

## ROOM SURVEILLANCE

- **MTX - MINIATURE 3V TRANSMITTER** Easy to build & guaranteed to transmit 300m @ 3V. Long battery life. 3-5V operation. Only 45x18mm. **3007KT £6.95**
- **AS3007 £11.95**
- **MTX - MINIATURE 9V TRANSMITTER** Our best selling bug. Super sensitive, high power - 500m range @ 9V (over 1km with 18V supply and better aerial). 45x19mm. **3018KT £7.95**
- **AS3018 £12.95**
- **HTPX - HIGH POWER TRANSMITTER** High performance, 2 stage transmitter gives greater stability & higher quality reception. 1000m range 6-12V DC operation. Size 70x15mm. **3032KT £9.95**
- **AS3032 £18.95**
- **MMTX - MICRO-MINIATURE 9V TRANSMITTER** The ultimate bug for its size, performance and price. Just 15x25mm. 500m range @ 9V (Good stability, 6-18V operation). **3051KT £8.95**
- **AS3051 £14.95**
- **VTX - VOICE ACTIVATED TRANSMITTER** Operates only when sounds detected. Low standby current. Variable trigger sensitivity. 500m range. Peaking circuit suppresses RF output. On/off switch. 6V operation. Only 63x38mm. **3028KT £12.95**
- **AS3028 £21.95**
- **HARDWIRED BUG/TWO STATION INTERCOM** Each station has its own amplifier, speaker and mic. Can be set up as either a hard-wired bug or two-station intercom. 10m x 2-core cable supplied. 9V operation. **3021KT £15.95** (kit 115x19mm). **3013KT £9.95**
- **AS3013 £21.95**



## TELEPHONE SURVEILLANCE

- **MTTX - MINIATURE TELEPHONE TRANSMITTER** Attaches anywhere to phone line. Transmits only when phone is used! Tune-in your radio and hear both parties. 300m range. Uses line as aerial & power source. 20x45mm. **3016KT £8.95**
- **AS3016 £14.95**
- **TRI - TELEPHONE RECORDING INTERFACE** Automatically records all conversations. Connects between phone line & tape recorder (not supplied). Operates records with 1.5-12V battery systems. Powered from line. 50x33mm. **3033KT £9.95**
- **AS3033 £18.95**
- **TPA - TELEPHONE PICK-UP AMPLIFIER/WIRELESS PHONE BUG** Place pick-up coil on the phone line or near phone earpiece and hear both sides of the conversation. **3055KT £11.95**
- **AS3055 £20.95**
- **1 WATT FM TRANSMITTER** Easy to construct. Delivers a crisp, clear signal. Two-stage circuit. Kit includes microphone and requires a simple open dipole aerial. 8-30VDC. PCB 42x46mm. **1006KT £14.95**
- **4 WATT FM TRANSMITTER** Comprises three RF stages and an audio preamplifier stage. Piezoelectric microphone supplied or you can use a separate preamplifier circuit. Antenna can be an open dipole or Ground Plane. Ideal project for those who wish to get started in the fascinating world of FM broadcasting and want a good basic circuit to experiment with. 12-18VDC. PCB 44x146mm. **1028KT £24.95**
- **AS1028 £39.95**
- **15 WATT FM TRANSMITTER (PRE-ASSEMBLED & TESTED)** Four transistor based stages with Philips BLY 88 in final stage. 15 Watts RF power on the air. 88-108MHz. Accepts open dipole, Ground Plane, 5/8, J, or YAGI configuration antennas. 12-18VDC. PCB 70x220mm. SWS meter needed for alignment. **1021KT £74.95**
- **SIMILAR TO ABOVE BUT 25W Output.** **1031KT £84.95**

- **LIQUID LEVEL SENSOR/RAIN ALARM** Will indicate fluid levels or simply the presence of fluid. Relay output to control a pump & add/remove water when it reaches a certain level. **1080KT £6.95**
- **STEREO VU METER** shows peak music power using 2 rows of 10 LEDs (mixed green & red) moving bar display. 0-30db. **3089KTT £11.95**
- **AM RADIO KIT 1** Tuned Radio Frequency front-end, single chip AM radio IC & 2 stages of audio amplification. All components inc. speaker provided. PCB 32x102mm. **3063KTT £10.95**
- **DRILL SPEED CONTROLLER** Adjust the speed of your electric drill according to the job at hand. Suitable for 240V AC mains powered drills up to 700W power. PCB: 48mm x 65mm. Box provided. **6074KTT £18.95**
- **3 INPUT MONO MIXER** Independent level control for each input and separate bass/treble controls. Input sensitivity: 240mV. 18V DC. PCB: 60mm x 185mm. **1052KTT £17.95**
- **NEGATIVE/POSITIVE ION GENERATOR** Standard Cockcroft-Walton multiplier circuit. Mains voltage experience required. **3057KTT £10.95**
- **LED DICE** Classic intro to electronics & circuit analysis. 7 LEDs simulate dice roll, slow down & land on a number at random. 555 IC circuit. **3003KT £9.95**
- **STAIRWAY TO HEAVEN** Tests hand-eye co-ordination. Press switch when green segment of LED lights to climb the stairway - miss & start again! Good intro to several basic circuits. **3005KTT £9.95**
- **ROULETTE LED** 'Ball' spins round the wheel, slows down & drops into a slot. 10 LEDs. Good intro to CMOS decade counters & Op-Amps. **3006KTT £10.95**
- **9V XENON TUBE FLASHER** Transformer circuit steps up 9V battery to flash a 25mm. Xenon tube. Adjustable flash rate (0.25-2 Sec's). **3022KTT £11.95**
- **LED FLASHER 1** 5 ultra bright red LED's flash in 7 selectable patterns. **3037MKT £5.95**
- **LED FLASHER 2** Similar to above but flash in sequence or randomly. Ideal for model railways. **3052MKT £5.95**
- **INTRODUCTION TO PIC PROGRAMMING.** Learn programming from scratch. Programming hardware, a P16F84 chip and a two-part, practical, hands-on tutorial series are provided. **3081KTT £22.95**
- **SERIAL PIC PROGRAMMER** for all 818/28/40 pin DIP serial programmed PICs. Sharingware software supplied limited to programming 256 bytes (registration costs £14.95). **3096KTT £13.95**
- **PICALL SERIAL & PARALLEL PIC PROGRAMMER** for all 818/28/40 pin DIP parallel AND serial PICs. Includes fully functional & registered software (DOS, W3.1, W95/8). **3117KTT £59.95**
- **ATMEL 89C051 PROGRAMMER** Simple-to-use yet powerful programmer for the Atmel 89C051, 89C2051 & 89C4051 uC's. Programmer does NOT require special software other than a terminal emulator program (built into Windows). Can be used with ANY computer/operating system. **3121KTT £24.95**
- **3V/1.5V TO 9V BATTERY CONVERTER** Replace expensive 9V batteries with economic 1.5V batteries. IC based circuit steps up 1 or 2 'AA' batteries to give 9V/18mA. **3035KTT £5.95**

- **STABILISED POWER SUPPLY 3-30V/2.5A** Ideal for hobbyist & professional laboratory. Very reliable & versatile design at an extremely reasonable price. Short circuit protection. Variable DC voltages (3-30V). Rated output 2.5 Amps. Large heatsink supplied. You just supply a 24VAC/3A transformer. PCB 55x112mm. Mains operation. **1007KTT £18.95**
- **STABILISED POWER SUPPLY 2-30V/5A** As kit 1007 above but rated at 5Amp. Requires a 24VAC/5A transformer. **1096KTT £32.95**
- **MOTORBIKE ALARM** Uses a reliable vibration sensor (adjustable sensitivity) to detect movement of the bike to trigger the alarm & switch the output relay to which a siren, bikes horn, indicators or other warning device can be attached. Auto-reset. 6-12VDC. PCB 57x64mm. **1011KT £12.95**
- **Box 2011XB £7.00**
- **CAR ALARM SYSTEM** Protect your car from theft. Features vibration sensor, courtesy/boot light voltage drop sensor and bonnet/boot earth switch sensor. Entry/exist delays, auto-reset and adjustable alarm duration. 6-12V DC. PCB: 47mm x 55mm. **1019KT £12.95**
- **Box 2019XB £8.00**
- **PIEZO SCREAMER** 110dB of ear piercing noise. Fits in box with 2 x 35mm piezo elements built into their own resonant cavity. Use as an alarm siren or just for fun! 6-9VDC. **3015KTT £10.95**
- **COMBINATION LOCK** Versatile electronic lock comprising main circuit & separate keypad for remote opening of lock. Relay supplied. **3029KTT £10.95**
- **ULTRASONIC MOVEMENT DETECTOR** Crystal locked detector frequency for stability & reliability. PCB 75x40mm houses all components. 4-7m range. Adjustable sensitivity. Output will drive external relay/circuits. 9VDC. **3049KTT £13.95**
- **PIR DETECTOR MODULE** 3-lead assembled unit just 25x35mm as used in commercial burglar alarm systems. **3076KTT £8.95**
- **INFRARED SECURITY BEAM** When the invisible IR beam is broken a relay is tripped that can be used to sound a bell or alarm. 25 metre range. Mains rated relays provided. 12VDC operation. **3130KTT £12.95**
- **SQUARE WAVE OSCILLATOR** Generates square waves at 6 preset frequencies in factors of 10 from 1Hz-100KHz. Visual output indicator. 5-18VDC. Box provided. **3111KTT £8.95**
- **PC DRIVEN POCKET SAMPLER/DATA LOGGER** Analogue voltage sampler records voltages up to 2V or 20V over periods from milli-seconds to months. Can also be used as a simple digital scope to examine audio & other signals up to about 5KHz. Software & D-shell case provided. **3112KTT £18.95**
- **20 MHz FUNCTION GENERATOR** Square, triangular and sine waveform up to 20MHz over 3 ranges using 'coarse' and 'fine' frequency adjustment controls. Adjustable output from 0-2V p-p. A TTL output is also provided for connection to a frequency meter. Uses MAX038 IC. Plastic case with printed front/rear panels & all components provided. 7-12VAC. **3101KTT £69.95**

## BARGAIN BUY!!

Great introduction to electronics. Ideal for the budding electronics expert! Build a radio, burglar alarm, water detector, Morse code practice circuit, simple computer circuits, and much more! No soldering, tools or previous electronics knowledge required. Circuits can be built and unassembled repeatedly. Comprehensive 68-page manual with explanations, schematics and assembly diagrams. Suitable for age 10+. Excellent for schools. Requires 2 x AA batteries. **ONLY £14.95** (phone for bulk discounts).

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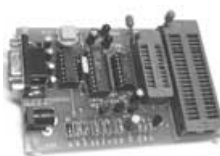
## ABC Mini 'Hotchip' Board



Currently learning about microcontrollers? Need to do something more than flash a LED or sound a buzzer? The ABC Mini 'Hotchip' Board is based on Atmel's AVR 8535 RISC technology and will interest both the beginner and expert alike. Beginners will find that they can write and test a simple program, using the BASIC programming language, within an hour or two of connecting it up. Experts will like the power and flexibility of the Atmel microcontroller, as well as the ease with which the little Hot Chip board can be "designed-in" to a project. The ABC Mini Board 'Starter Pack' includes just about everything you need to get up and experimenting right away. On the hardware side, there's a pre-assembled microcontroller PC board with both parallel and serial cables for connection to your PC. Windows software included on CD-ROM features an Assembler, BASIC compiler and an in-system programmer. The pre-assembled boards only are also available separately.

Order Ref	Description	inc. VAT ea
ABCMINISP	ABC MINI Starter Pack	£64.95
ABCMINIB	ABC MINI Board Only	£39.95

## ATMEL 89xxxx Programmer



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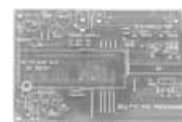
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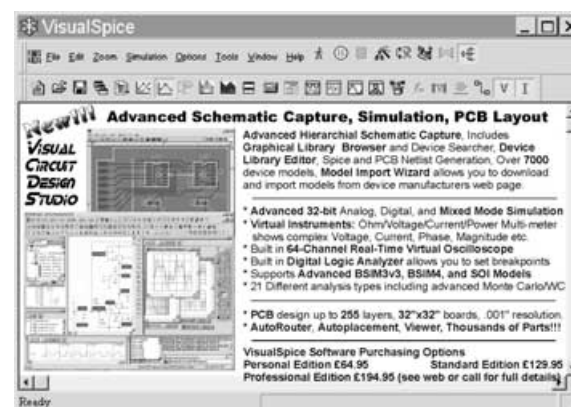
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## Advanced Schematic Capture, Simulation, PCB Layout



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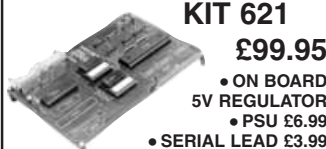
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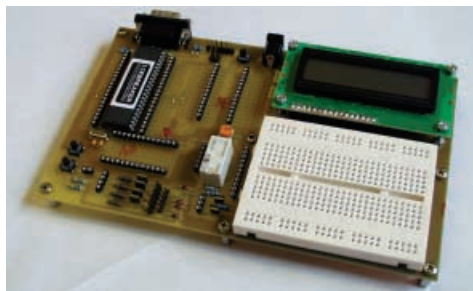
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Everyday Practical Electronics, February 2001





**Editorial Offices:**  
 EVERYDAY PRACTICAL ELECTRONICS EDITORIAL  
 ALLEN HOUSE, EAST BOROUGH, WIMBORNE  
 DORSET BH21 1PF  
 Phone: Wimborne (01202) 881749  
 Fax: (01202) 841692.  
**E-mail:** editorial@epemag.wimborne.co.uk  
**Web Site:** http://www.epemag.wimborne.co.uk  
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## SOMETHING SOGGY

I asked Marilyn what I should write my Editorial about this month; as she was gazing out of the window at the level of the River Allen just a few feet from my office, her reply was "Something soggy". Despite the flood protection wall (built through Wimborne at great expense a few years ago), our small office garden was awash because the water table was so high and the river just a foot or so from the top of the wall and our office floor level. At least at the time it had stopped raining – probably only for a day or so – and the water level was receding.

What has all this got to do with technology? Well, nothing really, and that is the point. Whilst we can monitor the water levels and the weather with all means of high tech gubbins, we can't do anything about changing it. We have satellites and the Internet, we have mind-boggling electro-mechanical data storage (see the Millipede News item last month), we can generate massive amounts of power by all sorts of means, but we still fail to protect ourselves and our homes from the effects of the elements. Our world is far more powerful than we are, and it will no doubt remain so.

## COMMERCIAL

Of course, we live in a commercial world where profit rules – if someone could make money from flood protection, like they can from communications, then we would soon see more barriers, pumps and pipes to protect vulnerable areas. Sadly, at present this is not the case, but maybe insurance companies and their regularly flooded customers could make schemes viable in the future. With, of course, electronics to monitor and control the systems.

There are few bounds to what we can achieve – as electronics developments continue to prove – if it is financially worthwhile. We are, however, still limited to what we can achieve when the elements decide to be nasty. However, next month we intend to show you how to generate your own lightning – see page 83.

*Mike Kenward*

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**Technical Editor:** JOHN BECKER

**Business Manager:** DAVID J. LEAVER

**Subscriptions:** MARILYN GOLDBERG

**Administration:** FAY KENWARD

**Editorial/Admin:** Wimborne (01202) 881749

**Advertisement Manager:**

PETER J. MEW, Frinton (01255) 861161

**Advertisement Copy Controller:**

PETER SHERIDAN, Wimborne (01202) 882299

**On-Line Editor:** ALAN WINSTANLEY

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CLIVE (MAX) MAXFIELD and ALVIN BROWN

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**E-mail:** techdept@epemag.wimborne.co.uk

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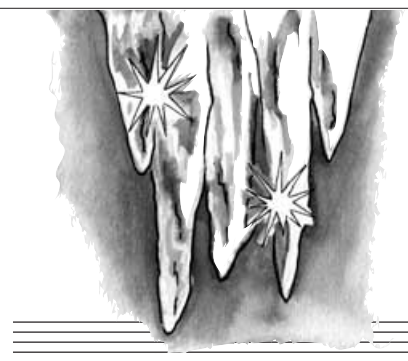
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# ICE ALERT

**TERRY de VAUX-BALBIRNIE**

*Red alert for a frost warning!*



**T**HIS project gives an indication of the outside temperature by the changing appearance of a three-colour light-emitting diode (l.e.d.). Above a certain threshold (nominally 6°C), it will be off. As the temperature falls, it will progressively appear Green (below 6°C), Yellow (below 4°C) and Red (below 2°C). These operating points could be changed over a small range to suit the application.

The Ice Alert will be found particularly useful by car drivers. However, readers will find many other applications for it. For example, gardeners could use it to monitor the temperature inside a greenhouse or at the ground surface from a point inside the house.

### EARLY WARNING

In many situations, the actual temperature of the surroundings does not need to be known. It is sufficient to be aware of it falling towards freezing point (0°C). When driving a car, steps may then be taken to reduce speed and be alert to the possibility of icy patches developing on the road.

*When used in a car, the Ice Alert must not be relied on by the driver or used as a substitute for normal vigilance. It is designed simply to provide additional information which may assist safe driving.*

*Experienced motorists know that there may be isolated frosty patches even when the general temperature is several degrees above freezing point. Since the sensor takes a few minutes to respond, isolated regions having a lower temperature may not be "seen".*

### APPEARANCE

The circuit is built in a small plastic box. On the front panel a 3mm tri-colour l.e.d. shows through a small hole (see photograph). A temperature sensor is connected through a length of twin wire to a piece of screw terminal block on the circuit board.

Depending on the application, the sensor will need to be protected against mechanical damage and weatherproofed. For automotive use, it will be attached to a suitable place underneath the car.

When installed in a car, the inter-connecting lead will be fairly short. However,

for other purposes it might be considerably longer. The system was used successfully with a lead 10m (33ft. approx.) in length. It could probably be made longer than this but the constructor would need to make the necessary tests.

### THERMAL CHECK

It may be possible to set up the circuit without calibration using common sense methods but this is not advised. For best results you will need to use a good quality laboratory-type thermometer capable of reading over the range 0°C to 10°C with an accuracy of 0.5°C.

Beware of inexpensive digital thermometers whose good resolution (say, 0.1°C) may deceive the user into thinking that they must be accurate. The author's was "out" by almost 1.5°C.

Calibration does not take long and it may be possible to borrow a suitable thermometer from a local school or college for an hour or two. Note that a photographic thermometer is not suitable because its scale often starts at 15°C.

### POWERING UP

When used in the car, the circuit receives current through the ignition switch so, while left unattended, no current

is drawn. With the ignition on, the current required by the prototype unit is between 7mA (with no colour showing) and 40mA with yellow. Such a low value imposes very little load on the charging system.

If the circuit is to be used for other than car purposes, it may be operated from a 9V battery (for example, the PP3 type) which can be accommodated inside the unit. When using such a supply, it will be necessary to include a pushbutton switch to power-up the circuit only when required. The current drawn will be less than that stated above for a 12V supply but, even so, continuous operation will soon drain the battery.

### CIRCUIT DESCRIPTION

The complete circuit diagram for the Ice Alert is shown in Fig.1. The temperature sensor consists of miniature bead thermistor, R1. This relatively simple, small and inexpensive device proved to have several advantages over temperature sensing i.c.s.

Note that the thermistor should be of the specified type if the circuit is to work without modification. Other types of thermistor could be used but the user may need to experiment with component values. More will be said about this later.

Ignore capacitor C1 for the moment. The thermistor R1 is connected in series with fixed resistor R2. This forms a potential divider connected across Zener diode D1. The Zener diode operates in conjunction with resistor R4 to provide a fixed 5.1V (nominal) supply.



*Completed Ice Alert. The small square of Velcro enables it to be easily installed below a vehicle dashboard.*

As the battery voltage rises or falls, the voltage appearing across resistor R4 will be the difference between that of the supply and the Zener breakdown voltage. Of course, the supply will need to exceed 5.1V for this to happen.

## RIISING VOLTAGE

As the temperature falls, the resistance of thermistor R1 increases and so does the voltage across it. At the operating temperatures (6°C, 4°C and 2°C), the voltages will be some 2.8V, 3.95V and 3.1V respectively. Note that these figures are approximate and are given only for the purpose of illustration.

By sensing the voltage across the thermistor, the tri-colour l.e.d., D2, may be made to operate at the correct temperatures. From now on, 6°C is referred to as the "upper fixed point", 4°C the "intermediate fixed point" and 2°C the "lower fixed point".

In operation, only a few microamps flow through thermistor R1. Its power dissipation is therefore only a matter of microwatts and this results in very low self-heating. Its ability to measure temperature is therefore hardly affected by the heating effect of the current.

Capacitor C1 is connected in parallel with the thermistor. If the sensor connecting lead is fairly long, it tends to pick up "hum" from a.c. power fields and this could cause the l.e.d.s to flicker near the operating points. The capacitor bypasses the a.c. while having no effect on the standing d.c. voltage. This allows the l.e.d.s to switch more smoothly.

## SMALL CHANGE

Integrated circuit IC1 is a quad operational amplifier (op.amp). This means that it contains four identical units contained in a single 14-pin package. Only three of the sections (IC1a, IC1b and IC1c) are actually used. The unused op.amp is "grounded" on the circuit board.

The inverting input of IC1a (pin 2), the non-inverting input of IC1b (pin 5) and the non-inverting input of IC1c (pin 12) are connected together and these, in turn, are connected to the top end of thermistor R1.

When the temperature of the thermistor is high, the voltage between these inputs and the 0V line will be low. When the temperature is low, the voltage here will be relatively high.

The remaining op.amp inputs (IC1a non-inverting input pin 3, IC1b inverting input pin 6 and IC1c inverting input pin 13) are connected to the sliding contacts of preset potentiometers VR2, VR1 and VR3 respectively. These provide adjustments to the operating points. The specified devices are multiturn trimmers which makes for very easy, accurate and convenient adjustment at the setting-up stage.

The ends of VR1 and VR2 tracks are connected in parallel and share fixed resistors R5 and R6 to form potential divider arrangements. The whole network is connected across D1, the 5.1V Zener stabilised supply. The fixed resistors limit the range of voltage available at the sliding contacts between some 2.5V and 3.6V.

With the specified thermistor this corresponds to a change from -5°C to +12°C approximately. This easily covers the range

of temperatures over which the device is likely to be used.

Preset potentiometer VR3 works in a similar way to VR1 and VR2 but it has its own pair of resistors R3 and R7 to form a potential divider. The range of voltage available is 2.2V to 3.3V and this corresponds to a change from -1°C to +18°C approximately.

Stabilising the voltage applied to the potential dividers gives a precision effect and helps to maintain operating accuracy.

## INPUT CONDITIONS

Look at IC1c first. Preset VR3 will be adjusted so that when the temperature sensed by the thermistor is 6°C (the upper fixed point) or less, the non-inverting input (pin 12) voltage will exceed the inverting one (pin 13).

Under these conditions, the output at pin 14 will be high and current will flow through current-limiting resistor R10 into the base (b) of transistor TR1. This turns it on and the collector (c) goes low. The l.e.d. (D2) is now enabled because there is a conducting path from the common cathode (k) to the 0V line.

When a higher temperature than the upper fixed point is detected, the input conditions are reversed and IC1 pin 14 will be low. With TR1 off, the conducting path is removed and the l.e.d. will not operate. A full description of how the tri-colour l.e.d. works is given later.

Preset VR2 is adjusted so that the voltage at IC1a non-inverting input (pin 3) is more than that at the inverting one (pin 2) for temperatures above 2°C (the lower fixed point). During this period, pin 1 is high and current can flow through current-limiting resistor R8 and the green l.e.d. section. Green will, therefore, show between the upper and lower fixed points.

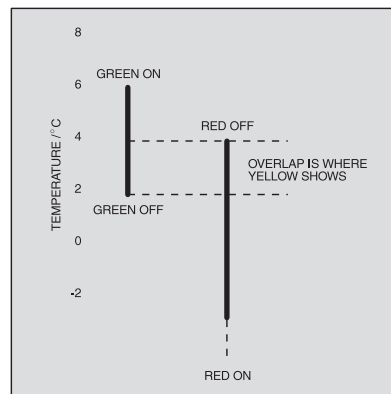


Fig.2. Tri-colour l.e.d. switching levels.

Preset VR1 will be adjusted so that the inverting input voltage of IC1b (pin 6) is less than that at the non-inverting one (pin 5) below 4°C (the intermediate fixed point). During this time, pin 7 will be high and the red l.e.d. section operates through current-limiting resistor R9. Red will show with temperatures below the intermediate fixed point.

This is best illustrated with the diagram shown in Fig. 2. The overall effect is that nothing will happen above the upper fixed point (because the l.e.d. is disabled), *green* will show down to the intermediate fixed point, *yellow* down to the lower fixed point (because both l.e.d. sections are on) and *red* below the lower fixed point (because the green section goes off).

## COLOURFUL DESCRIPTION

For those who are not familiar with the tri-colour l.e.d., a brief description follows. Unlike a conventional l.e.d. this has *three* pinout leads – not two. The centre one is the common cathode (k) and is connected

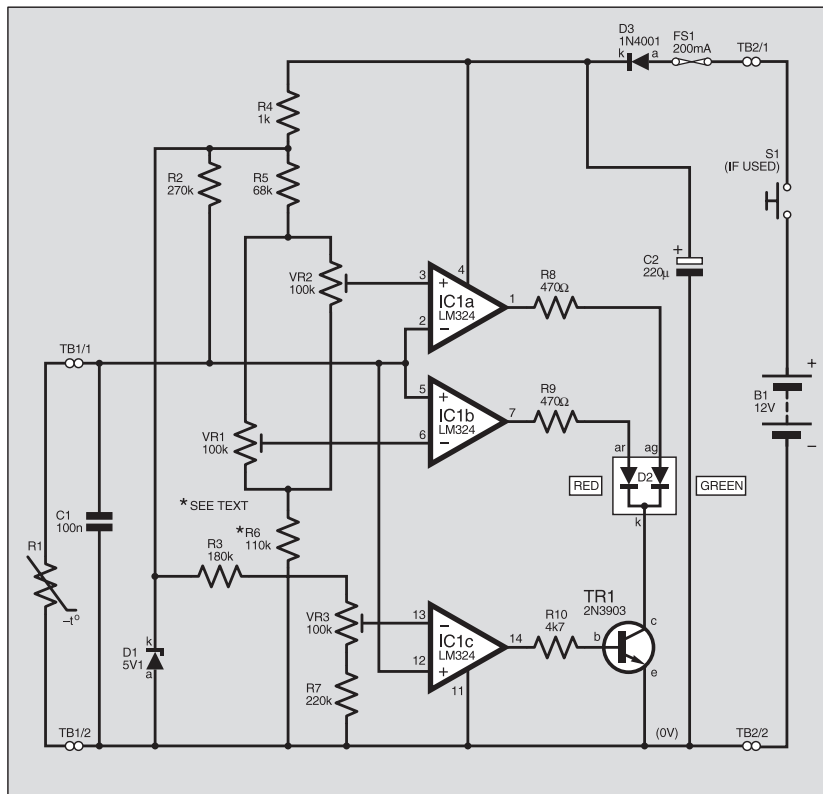


Fig.1. Complete circuit diagram for the Ice Alert.



to 0V. The other leads are the anodes of separate red and green l.e.d.s. (ar and ag respectively) contained within a white translucent plastic package.

With current flowing through the red section only, the effect will obviously be red. Similarly, when current flows through the green section only, the effect will be green.

However, if *both* l.e.d. sections pass current, the red and green light diffuse and mix in the milky white plastic body to give a "yellow". Any student of physics will know that red light (a primary colour) mixed with green light (a primary colour) gives the secondary colour, yellow. Note that this is not the same as mixing red and green paint!

## COMPONENTS

### Resistors

R1	miniature bead thermistor: resistance at 25°C 150k and at 0°C 535k approx.
R2	270k
R3	180k
R4	1k
R5	68k
R6	110k (or 100k and 10k in series – see text)
R7	220k
R8, R9	470Ω (optional 330Ω for 9V battery – see text) (2 off)
R10	4k7
All 0.25W 5% carbon film, except R1	

See  
SHOP  
TALK  
page

### Potentiometers

VR1, VR2	
VR3	100k multiturn preset, vertical mounting, top adjustment. Pins to be in line and having a spacing of 2.5mm (3 off)

### Capacitors

C1	100n metallised polyester
C2	220μ radial elect. 25V

### Semiconductors

D1	5V1 0.5W Zener diode
D2	3mm tri-colour l.e.d.
D3	1N4001 rect. diode
TR1	2N3903 npn transistor
IC1	LM324 quad op.amp

### Miscellaneous

FS1	200mA 20mm quick-blow fuse and p.c.b. mounting fuse clips
S1	miniature s.p.s.t. push-to-make switch (for internal battery use)

Printed circuit board available from EPE PCB Service, code 287; plastic box, external size 75mm x 56mm x 25mm (larger if using an internal battery); 14-pin d.i.l. socket; 3A automotive-type wire; 2-core stranded connecting wire as required; auto-type connectors; silicone sealant (see text); solder etc.

Approx. Cost  
Guidance Only

**£16**  
excluding batt.

## PROTECTION

A supply is connected to the circuit through on-off switch S1 (if powered using an internal battery), fuse FS1 and diode D3. This latter component provides reverse-polarity protection. Thus, if the supply were to be connected in the opposite sense, the diode would fail to conduct and nothing would happen.

Fuse FS1 will blow if the current rises excessively in the event of a short-circuit. This is vital when a car battery is used because these can deliver an enormous current under short-circuit conditions. This could melt p.c.b. tracks, cause burns and be a general fire hazard.

Since the car charging circuit provides a rather unsmooth output, capacitor C2 is included to condition it and provide a suitable supply for the rest of the circuit.

## CONSTRUCTION

Construction is based on a single-sided printed circuit board (p.c.b.). The topside component layout and full-size underside copper foil track master are shown in Fig.3. This board is available from the EPE PCB Service, code 287.

All components, apart from the thermistor (R1) and on-off switch S1 (if used) are mounted on the p.c.b. Begin construction by drilling the two fixing holes and soldering the link wire in place as indicated. Note that this is difficult to do after preset VR2 has been soldered in position.

Add the pieces of screw terminal block, the 14-pin d.i.l. socket for IC1 (but do not insert the i.c. itself yet) and the fuse clips. If fuse clips such as those shown in the photograph are not available, use a p.c.b. mounting fuseholder or a small fuseholder mounted off-board.

Solder all fixed resistors and capacitor C1 in position. Note that if a 9V battery is to be used as the power supply, resistors R8 and R9 could be reduced to 330 ohms if the l.e.d. does not turn out to be bright enough in use. In the interests of long battery life, however, leave them as they are.

To make up the specified value for resistor R6, you could use a 100k (kilohms) and a 10k unit connected in series (as in the prototype unit). Add capacitor C2 and diodes D1 and D3 taking care over the polarity of these components. The orientation of D1 is correct as shown.

To the beginner, it may seem as if it is the wrong way round. However, because it is a Zener diode it operates in reverse bias. The negative lead of C2 is clearly indicated and is slightly shorter than the positive one.

Next, solder the preset potentiometers in place. These should be mounted as shown in Fig.3 and the photograph (with the adjustment screw on VR1 and VR2 at top right and for VR3 bottom right). The circuit will work if they are mounted in the opposite sense but the instructions given later regarding their adjustment will be incorrect and the effect might be confusing. Note that the preset potentiometers should be of the type having a top adjustment screw and with the pins in line (rather than in the form of a triangle).

## TRI-COLOUR L.E.D.

Now look at the tri-colour l.e.d. (D2). The common cathode (k) lead is the centre one and the red and green anode (ar and ag respectively) are on each side of it. It is important to solder this device with the anode leads located correctly. If they are incorrectly placed, the colours will be interchanged and this would give strange results at the setting-up stage.

The longer of the two anode leads is the red and the shorter one green, see inset diagram in Fig.3. After taking note of which is which, cut them to a length of 10mm, bend them carefully through right angles and solder them in position.

If you lose track of which lead is which, the specified unit is different in the way the end leads enter the body. If you look carefully, you will see that the red one is bent through a right angle whereas the green one makes an obtuse angle.

Adjust the preset potentiometers in the following way (assuming they are of the specified pattern and have been mounted as indicated in Fig.3): VR1 and VR2 fully clockwise and VR3 full anti-clockwise. Note that these devices usually click if the screw continues to be turned after the sliding contact has reached the ends of its track.

Finally, place a 200mA quick-blow fuse between the fuse clips and insert IC1 into its socket taking care over the orientation.

## TESTING

*Do not test the unit by immersing the thermistor in water. This is because tap water is a reasonably good conductor of electricity and it would effectively short-circuit the leads. This would give an apparent reduction in the resistance of the thermistor and lead to totally incorrect results.*

Do not wait until the thermistor has been waterproofed or the slower response time would make calibration inconvenient.

The circuit should be tested and adjusted using a 9V battery (an alkaline PP3 type would be suitable). This should be done before mounting the p.c.b. in its case. In this way, any small faults may be corrected more conveniently.

Since water must be avoided for the reason stated above, use cooking oil for calibration. This is a non-conductor so will not interfere with correct operation. Place a small amount of this in a small plastic container to provide a depth of 30mm approximately. Put it in a freezer for 15 minutes or so until the temperature has fallen to -5°C or thereabouts.

While waiting for the oil to cool, prepare the thermistor. Using two sections of a 2A screw terminal block, connect the thermistor to a short piece of light-duty twin wire. Connect the other ends to terminal block TB1 on the p.c.b. Connect a PP3 battery snap (or as required) to TB2 taking care over the polarity – red (+) wire to TB2/1 and black (-) wire to TB2/2.

When the cooking oil is taken out of the freezer, it may have partially solidified. If necessary, wait until it softens then place the thermometer bulb and thermistor in it. Make sure both the thermometer bulb and thermistor are well covered. Connect the battery – the l.e.d. should light up red.



## STIRRING IT

With the aid of an assistant, keep the oil stirred constantly and take a continuous note of its temperature.

When the temperature rises to 2°C, adjust preset VR2 anti-clockwise to the point where the green l.e.d. just comes on (the display will now show *yellow*). When the temperature reaches 4°C, adjust VR1 anti-clockwise so the red l.e.d. just goes off (the colour is now *green*). When 6°C is reached, adjust VR3 clockwise until the l.e.d. goes off (no colour shows).

You may need to repeat the procedure several times to obtain the required operating points.

## BE PREPARED

The following assumes that the Ice Alert circuit is to be used in a vehicle. If not, work accordingly.

Decide on a suitable position for the main unit. The l.e.d. should be clearly visible from the driving position. Attach it using a "Velcro" pad.

Decide on a suitable site for the sensor. This needs to be placed as low as possible or the temperature indicated may not be a true reflection of that near the road. Also, it must be kept as far away as possible from the exhaust system or anything else which becomes hot.

There will probably be a suitable site in the region of the front bumper. Try to find a place where there will be a free flow of air around the sensor unit while the car is moving.

very small and will not cause any problems. Note, however, that the l.e.d. will go *off* if this were to happen. Should the wire break, the l.e.d. would show red.

## PROTECTION RACKET

The thermistor (R1) now needs to be waterproofed and protected. Use a short piece of plastic tube to contain it. In the prototype unit, the end of an old phono plug was used.

Push the ends of the connecting wires through the hole in one end of the tube and solder them to the thermistor using minimum heat to prevent damage. Do not cut down the leads (or if you have to, remove the minimum amount) since even more heat would reach the thermistor during soldering and there would be a greater risk of damage.

Push the thermistor and soldered connections so they are completely inside the tube. Making certain the soldered joints are kept

well separated, fill the tube with clear silicone sealant. This must be of a type which cures to become tough and rubbery. Use the material available in a small tube from various manufacturers (such as *Loctite Clear Adhesive Sealant*). Products such as "bathroom sealant" have not been tested and might not be suitable.

the material to harden. It must now be handled with care. Take care not to put the connecting lead under any strain.

## CASING UP

The p.c.b. should now be attached inside a small plastic case. Where the unit is being used in a car, the box need only be large enough to accommodate the circuit panel plus a little extra to allow for connections to be made to the p.c.b.-mounted terminal blocks.

If an internal 9V battery is used, you will need a larger box. You also need to include a push-to-make switch (S1) in the positive supply lead to conserve battery life.

Measure the position of the l.e.d. on the p.c.b. and drill a hole in the front of the box to correspond with it. This should only be large enough to allow the tip of the l.e.d. to pass through.

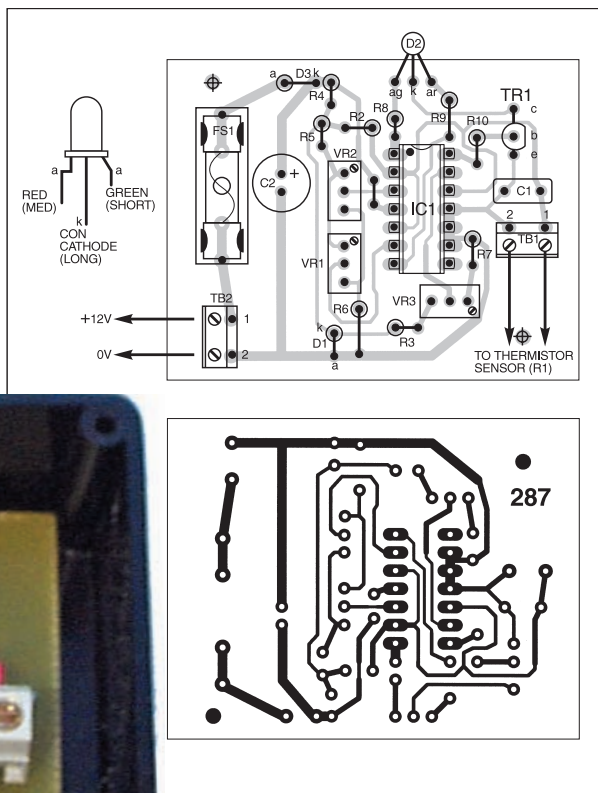


Fig.3. Printed circuit board component layout and full size foil master pattern.



Ice Alert completed circuit board secured inside a small plastic box with nylon fixings. The tri-colour l.e.d. can be seen at the top.

Measure the length of light-duty two-core wire needed to connect the thermistor sensor to the main unit. This does not need to be of automotive quality but it must be of the *stranded* type. Do not use single-core wire or it would break easily in service.

"Ordinary" (non-automotive) wire may be used because, in the event of a short-circuit between the "live" sensor wire and the car chassis (0V) or between the wires, the maximum current which can flow is limited by resistors R2 and R4 in series. This will be

Check that all bare wires and the thermistor itself are deeply embedded in the silicone material and allow it to harden. It is absolutely essential for the thermistor and its end leads to be completely waterproofed and great care must be taken over this process. The operating points will be greatly affected by even small traces of moisture. The completed sensor appears in the photograph.

Leave the sensor for 24 hours (or whatever curing time is shown on the tube) for



The bead thermistor temperature sensor encased in a phono plug.



Hold the p.c.b. in position just above the base of the box and *gently* bend the l.e.d. leads as necessary so its tip takes up the correct position in the hole drilled for it. Mark the positions of the p.c.b. fixing holes. Remove the p.c.b. again and drill these through.

Make a hole for on-off switch, S1 (if used). Drill a small hole in the side near terminal block TB2 position for the power supply wires (unless an internal supply is used) and a further one near TB1 for the sensor wires.

Attach the p.c.b. using small *nylon* fixings. Place plastic washers on the bolt shanks to keep the soldered joints on the underside clear of the base of the box. Make sure the l.e.d. leads are not left under any strain.

## INSTALLING

Attach the thermistor sensor in its chosen position. This can possibly be done using a small plastic clip or some epoxy resin adhesive. It is important to support the connecting wire close to the sensor using a further clip. This will remove the strain at the point where it enters the tubular "casing".

Route the sensor wire back to the main unit. *Note: whenever it passes through a hole in metal, a protective rubber grommet must be used.* Pass the wires through the appropriate hole in the box and connect them to TB1.

## CONNECTING UP

Connections now need to be made to the car electrical system. ***Before proceeding, the car battery must be disconnected. (Check the car's manual to make sure it is OK to disconnect the battery before proceeding.) This is essential procedure. If you do not do it, there is risk of causing a short circuit which could result in wires becoming red hot and burns to the skin.*** The supply must be made using light-duty *auto-type* cable and with proper car-type connectors.

If you have a radio of the type having a numerical code, make sure you have this available to re-enter it when the supply is re-established. Also make sure you know how to do this by referring to the instructions supplied with the radio.

A safer alternative to making direct connections would be to plug the unit into the cigar lighter socket. This method is rather less attractive but does have the advantage of being quick and easy.

## WIRING UP

For permanent wiring, connect TB2/1 to a point via an existing fuse which is live only when the ignition is switched on and TB2/2 to an existing earth point (car chassis). It may be that the easiest place to obtain a feed to the circuit is at the rear of the radio or audio system. Connections to existing wires may be made using "snap-lock" connectors.

If you decide to use the wires leading to the radio, identify the correct positive one to use because there are likely to be two of them. One is a constant +12V feed to maintain the memory settings and the other will probably be via the "car radio" position on the ignition switch. The latter would be suitable for the new circuit.

If any wire passes through a hole in metal, a rubber grommet must be used to prevent cutting by the sharp edge and possibly causing a short-circuit. Apply strain relief to both the sensor and power supply wires inside the case by applying tight cable ties to them.

Re-connect the car battery and switch on the ignition. The l.e.d. should be off (assuming the temperature outside is above the upper fixed point). You could wait for a cold day to make a final test. However, a rough check on operation could be made by using a freezer spray applied to the sensor. Remember, it will take some time to respond.

When using the Ice Alert for other than car purposes, it may be necessary to place the sensor more than 10m from the main unit. This could be necessary, for example, if you wished to monitor the temperature in a remote greenhouse from a point inside the house. In cases such as these, check that the l.e.d. sections operate relatively "cleanly" (without too much flickering).

This type of problem could probably be reduced by using light-duty single screened cable for the inter-connecting lead instead of ordinary twin wire. The screening would be connected to 0V (that is to TB1/2) and the inner core to TB1/1. Note that the resistance of any wiring used will be much

less than that of the thermistor. The effect of the resistance of the connecting lead is therefore negligible.

## CHOICE OF THERMISTOR

The circuit will work correctly if the specified thermistor is used. However, it is appreciated that some readers will be restricted in their choice of thermistor.

If you must use one of a different pattern, use the usual "negative temperature coefficient" variety (that is, as the temperature *rises*, the resistance *falls*) having a resistance of some hundreds of kilohms at 0°C. Halve this figure and select the nearest available value of fixed resistor. Use this in the R2 position.

If the circuit now works correctly, all well and good. If not, use link wires instead of resistors R3, R5, R6 and R7. This will give the maximum range of adjustment of the preset potentiometers (from 0V to 5.1V). Although they may be more awkward to adjust, it should now be possible to set up the correct operating points.

## RESPONSE TIME

Although it takes a while for the sensor to respond to large changes in temperature, this is not generally a problem. While the car is parked, the sensor will assume the temperature of the surrounding air.

When driving along, the changes will probably not be very great and the sensor should respond within a few minutes. If the sensor is placed in the air flow, the response will be faster.

When used in a vehicle, the Ice Alert **MUST NOT** be relied on by the driver or used as a substitute for normal driving vigilance. It is designed simply to provide additional information which may assist safe driving. □



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## TEXT FILES NOT IMMUNE TO VIRUSES

Contrary to what is widely believed, the latest computer viruses *can* live and propagate through text files. Barry Fox alerts us.

**V**IRUS wars have taken a nasty new twist. E-mail viruses are getting past anti-virus software by disguising themselves as help files which hide in plain text that had previously been thought safe. Anti-virus software must work in completely new ways to trap them. There is widespread confusion over what systems are at risk and how best to protect them.

### VIRUS EXECUTIVES

Until recently viruses spread as executable code programs, attached to plain text E-mails. The text message encourages the recipient to open the attachment by clicking on it. This runs the program which deliberately corrupts data on the PC's hard disk, makes copies of itself and attaches them to outgoing E-mails, so as to spread the infection. Traditional anti-virus software scans attachments before they are opened, looking for the "signature" of known viruses. PC users have felt safe to open and read E-mails as long as they do not click on any attached file.

Bubble Boy, the first virus to infect without an attachment, exploited a security loophole in Microsoft's Outlook Internet mail reader. The virus code is written as lines of HTML code which are included in the text message. Outlook treats the text as an Internet page and runs the code to release the virus. Expert PC users who understand the risk, and also understand Microsoft's jargon, can download a program which modifies Outlook to stop it being fooled (<http://www.microsoft.com/technet/security/bulletin/ms00-046.asp>).

### BEWARE SILLY TITLES

Now a new virus, confusingly known as Verona, Romeo and Juliet or BleBla plays a much more devious trick which is likely to fool a wider range of Internet mail readers. A text message with a silly title, such as Hey You, Sorry or From Shake-Beer, arrives with two attached files, a Help file called **Myjuliet.chm** and a program called **MyRomeo.exe**. Just reading the text message makes Windows save the two attachments to its standard Temporary folder where the Help file automatically runs and triggers the program to infect the PC. This then tries to send copies to other addresses stored in the mail reader.

Romeo and Juliet does no damage to the hard disk and has not spread because the Polish Internet servers it uses to spread infection were quickly shut down. So there has been very little publicity.

"But the code now exists as a template which the hacker community can share and modify to make it much more

dangerous" warns Nick Galea, CEO of GFI, a Maltese company which makes software to protect office networks. "Then we shall see PCs damaged as soon as people read a text message."

Galea thinks that protection software must start checking E-mails for the effects viruses may cause, not just known signatures.

### SYMANTEC'S WARNING

Eric Chien, chief researcher at Symantec's Anti-Virus Centre, warns that this is much easier with office networks than standalone PCs. A network server can store and check all incoming E-mails before distributing them to office staff. Individual PCs collect E-mail direct from the Internet. Symantec has developed a system called PopProxy which shunts incoming E-mail into a buffer file on the PC, and checks plain text for tell-tale code. The user only sees the mail after it has

been checked. Symantec has built PopProxy into the latest version of its Norton Anti-Virus software, NAV 2001, but done surprisingly little to explain or promote it.

Graham Cluley of Sophos thinks the only long term solution is to use proprietary E-mail services and readers, such as Compuserve, AOL or Cix, which treat text only as text, ignore any lines of code which are embedded and never dress plain text up as HTML.

"Better to choose a safe reader in the first place, than go on spending money on anti-virus software that tries to make unsafe readers safe". Opinions differ on what Internet readers are safe, but the one thing everyone agrees on is that Microsoft, the most widely used, has been the least safe. All too often it sends the text twice in the same message, once plain and safe and once in HTML and risky. The sender is not usually aware of this.

## 20MHz FUNCTION GENERATOR



VANN Draper Electronics, the manufacturer and world-wide distribution company for Grundig *digimess* Instruments, has announced a new 20MHz function generator.

The FG100 provides a wide frequency range of 0.5Hz to 20MHz with a high accuracy of 0.5 per cent monitored by an internal microprocessor. Output wave shapes include sine, triangle, square and sawtooth, with variable symmetry enabling pulse signals to be produced.

A back-lit alphanumeric display provides concise readings of settings and frequency, as well as communication modes when using the built-in RS232C interface.

Other key features include internal sweep, d.c. offset, variable output level from 10mV to 10V, plus sync output. It operates as stand-alone or PC controlled.

Priced at £199 the FG100 is available direct from Vann Draper or their authorised distributors. For more details contact Vann Draper Electronics Ltd, Dept EPE, Stenson House, Stenson, Derby DE73 1HL. Tel: 01283 704706. Fax: 01283 704707. E-mail: [sales@vanndraper.co.uk](mailto:sales@vanndraper.co.uk). Web: [www.vanndraper.co.uk](http://www.vanndraper.co.uk).

## B.A.E.C. SEEKS PIC ENTHUSIASTS!

THE Editorial of the British Amateur Electronics Club's recent newsletter laments the decline in contributions to it. The Editor, George Burton, expressed the opinion that the B.A.E.C. should follow *EPE*'s example and place a strong emphasis on the use of PIC microcontrollers.

George asks, "How many of our members have seen a PIC chip let alone used one? It is these members I am trying to find. We have to start using these multi-purpose components or shall fade away – reminiscing how we used to do it".

We suggest that any reader who knows about PICs (and there are many thousands of you) and would like to join the B.A.E.C. and share their knowledge with other members through contributions to the Newsletter should do so *now*. You will be warmly welcomed, as will other non-PIC electronics enthusiasts.

The Club is open to anyone interested in electronics – and that's all of you! (We know that a *trickle* of you have joined recently, well done. How about a *flood* – dare we mention the word in the present climate?)

The B.A.E.C. has existed for many decades and deserves your support so that it can progress into the future. We encourage you to contact the Chairman, George Burton, 581 Fishponds Road, Fishponds, Bristol BS16 3AA. Tel: 0117 9654800. E-mail: [prontaprint.bristol@cableinet.co.uk](mailto:prontaprint.bristol@cableinet.co.uk). Web: <http://members.tripod.com/~baec>. Mention *EPE* when contacting George.

## TRAFFIC REPORTS COMPETITORS

By Barry Fox

THE cellphone companies are spending billions on licences to spend more billions building third generation networks. The last thing they need is competition from conventional radio services which can offer 3G features at far lower cost.

After ten months of trials a Californian startup, backed by Texas Instruments, Motorola and Paul Allen, is offering digital radio broadcasters a system which competes head-on with 3G. Command Audio lets drivers listen to the latest traffic, weather, sports and news information, the moment they get in the car. While driving they can switch between music in real time, and the latest news updates.

The technology was developed and patented by Command Audio in Redwood City and John Ryan, who heads up Macrovision, the world leader in video copy protection. A control centre compresses a wide selection of conventional radio programmes into 2-4Kbps streams and broadcasts them as data channels. The receiver, which looks like a chubby TV remote control, has memory chips which continually store the last eight hours of sub-channel audio, for instant skip and scan access at the press of a button.

Command has trialled the system in Denver and Phoenix using data subcarriers on FM radio stations and prototype handsets made by RCA and Thomson. Most countries, except the US, are adopting the European digital radio system which can carry much more digital data than FM radio – around 1.5Mbps of which some 75 per cent is used for music and the rest set aside for data (the UK allocation is 20 per cent or 230Kbps but could be increased; Singapore already allows 35 per cent). So far digital broadcasters have used their data capacity to deliver Internet pages but Command believes drivers would prefer on-demand audio.

Quentin Howard, Chief Executive of the UK's commercial digital radio network Digital One, has long enthused over data by radio. He says: "We have built a radio network that can deliver very high data rates to an unlimited number of users from just 70 transmitters. The new cellular networks will each require some 6000 transmitters and will never be able simultaneously to serve the same number of consumers as we can".

Howard thinks Command Audio is a "neat idea" but questions whether listeners will be prepared to pay the \$12 a month subscription which Command is talking about.

## MAPLIN CD-ROM

MAPLIN Electronics' latest CD-ROM catalogue has recently been released. It contains around 15,000 products, ranging from individual components to state-of-the-art electronic equipment.

The CD-ROM, which has been developed in HTML, is designed with the same functions as Maplin's website and runs on Internet Explorer 5 (available to download from the CD-ROM).

The new "Web-enabled" CD-ROM allows you to construct your order offline. Once Submit has been pressed the browser is launched automatically allowing orders to be stock checked and processed for sameday despatch.

To receive a copy of the CD-ROM, which costs £1.99, contact the Order Line on 0870 264 6000 and quote order code CQ07, or click on the icon at [www.maplin.co.uk](http://www.maplin.co.uk). Maplin's press release states the contact address as Maplin Electronics, Valley Road, Wombwell, Barnsley S73 0BS. Mention *EPE* when contacting Maplin.

## RIPPING MUSIC

By Barry Fox

MP3 ripping is now a living room reality. Korean electronics giant Samsung is the first big brand name in household audio to offer a range of mini, midi and micro hi-fi systems with integrated MP3 ripper. Until now consumers have had to use a PC to download MP3 music from the Internet or "rip" CDs by converting the content into MP3 (MPEG-1, Layer 3) code. The PC must then be connected to a portable solid state player like the Diamond Rio, to transfer the music for portable playback.

Three new home audio stacks from Samsung (costing between £350 and £500) have a CD player, built-in MP3 encoder and dockable Yepp solid-state player with 32MB SmartMedia card for 30 minutes recording time. The owner just plays a disc while transferring the music to the portable, without needing to own a PC or know anything about computers and computing.

## ROBOT KITS

AN E-mailed newsletter from Quasar Electronics informs us that "We have introduced a range of educational electronic robot kits. We really like them. They are high quality, excellent designs, good fun and educational. What more could you ask for in life . . .". Indeed!

Quasar have lots more educational kits (and others). You will find info about them at: [www.quasarelectronics.com/educational-electronic-projects.htm](http://www.quasarelectronics.com/educational-electronic-projects.htm). There is also a mirror site at [www.electronic-kits-and-projects.com/home.htm](http://www.electronic-kits-and-projects.com/home.htm).

Tel: 01279 306504.

E-mail: [sales@quasarelectronics.com](mailto:sales@quasarelectronics.com).

Note Quasar's fax: 07092 203496.

## SQUIRES TOOLS

SQUIRES Model and Craft Tools 2001 catalogue has recently arrived at HQ. It contains an excellent (dare we say "fully comprehensive"?) variety of the tools and associated modelling accessories that any self-respecting hobbyist requires. The electronic components range has been expanded and all goods are available by post-free mail order.

In over 400 well presented and itemised pages, Squires' cat is a *must* to have on your workbench. It's also *free of charge* – just contact Squires and they'll send you a copy:

Squires Model and Craft Tools, Dept EPE, 100 London Road, Bognor Regis, W. Sussex PO21 1DD. Tel: 01243 842424. Fax: 01243 842525. (No Web as yet, but it's on its way!)

## EOCS Website Launched

THE Electronic Organ Constructors Society website [www.eocs.org.uk](http://www.eocs.org.uk) is now on-line. So far as is known, the EOCS is the only international society devoted to amateur electronic organ building. If this is your interest, have a good browse of the site, and even participate in the EOCS equivalent of our Chat Zone.

You can also contact the Society via Trevor Hawkins, Hon. Sec., EOCS, 23 Blenheim Road, St Albans, Herts AL1 4NS. Tel: 01727 857344. Mention *EPE*.

# New Technology Update

*Last month Ian Poole discussed organic lasers. He now looks at the emerging technology of organic l.e.d.s.*

**S**URPRISINGLY the cathode ray tube still offers the best performance for many display applications. Modern alternatives, including liquid crystal displays, electro-luminescent displays and a variety of other types, have not managed to capture the market to the degree achieved by the c.r.t.

## Organic Displays

However, a new breed of displays is beginning to appear. Termed Organic Light Emitting Diode (OLED) displays, they offer some real advantages over displays that are currently available. Unlike traditional liquid crystal displays (l.c.d.s) these OLED displays are self-luminous and do not require back-lighting. As back-lights take up additional space it means that OLED displays can be made thinner and more compact than many other types.

A further advantage is that OLED displays have a very wide viewing angle. This can be up to 160 degrees, even in bright sunlight.

They also consume relatively little power, and can run from supplies between 2 and 10 volts. This makes them very attractive for many applications where voltage supplies and power consumption are an issue.

A further advantage of the low power consumption is an improvement in EMC performance. As drive levels are low, the risk of radiating signals is much reduced, and this is particularly useful when designing products for which regulations on emissions are relatively tight.

## Operation

There are two basic types of display, active and passive. However, they both rely on the same basic principles. The basic OLED cell structure consists of four layers of organic material positioned between a metallic cathode and a transparent anode. The organic layers comprise a hole injection layer, a hole transport layer, an emissive layer and an electron transport layer, as shown in Fig.1.

A voltage is applied across the cell and positive and negative charges recombine in the emissive layer as in an ordinary diode. As a result of the recombination light is produced. Most of the recombination takes place in the emissive layer, although some does occur elsewhere. To improve the efficiency the design of the structure is optimised to ensure this recombination takes place in the emissive layer where light is produced. Further enhancement of the light output is gained by doping the emissive layer with a small level of highly fluorescent molecules.

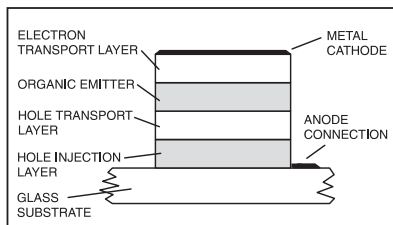


Fig.1. OLED Structure

## Passive displays

Passive OLED displays are less complicated than their active counterparts. They are well suited for low cost and low information content applications like alphanumeric displays. They are formed by providing an array of OLED pixels. The cathodes and anodes are arranged in rows and columns and by selecting the relevant row and column the required pixel can be activated. These can be scanned and successively lit to give the required pattern.

Kodak have developed a unique method for fabricating these devices. The simplicity of the process means that costs are kept to a minimum.

First a "rib" or "base and pillar" structure is pre-formed on patterned anode lines. The organic materials are then deposited and the nature of the deposition process means that the OLED display panel with the required electrical isolation for the cathode lines is automatically formed.

One of the major advantages of this method of fabrication is that no new processes have been introduced and it can be easily be adapted to high throughput manufacturing.

## Active displays

As the name suggests, the passive display does not include any additional electronics. This limits its application to the more simple displays where the individual rows and columns can be easily accessed. Once the pixel count rises to the level that graphics can be displayed it becomes necessary to include the drive circuitry within the display itself. This is normally included in the substrate where a back plane can be constructed. In this way a very sophisticated high resolution graphics display can be created, suitable for applications like television screens, computer monitors and the like.

The use of polysilicon technology is key to the manufacture of these displays because it provides a high carrier mobility. This gives the thin film transistors (TFT) that are used a high current carrying capacity and fast switching speed essential for the correct operation of these displays.

Each individual pixel in the display can be addressed separately via the electronic circuitry in the back plane that consists of the TFTs and associated capacitors.

The basic circuitry is relatively simple and combined with the straightforward fabrication of the display itself, there are no intrinsic limitations to the pixel count, resolution or actual size of the display. This makes it particularly attractive for high resolution displays of the types needed for televisions and computer monitors.

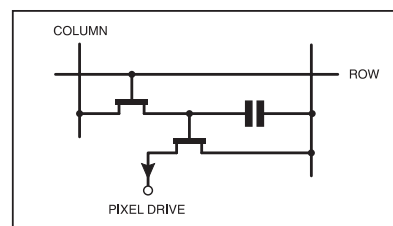


Fig.2. Active display driver circuit

## Missing pixels

Missing pixels occur on any large display. It is normal to allow displays to be sold that have a small number of defects. If this were not done then the yields would be unacceptably low and prices exceedingly high. When this occurs with an OLED display the pixel is left dark, and this is unlikely to be noticed by the eye. Faulty l.c.d. displays often produce a point of light and this is far more visible.

## Future

Whilst much of the work that has been described has been undertaken by Kodak, other companies are also working on the displays and forming alliances that will enable production to move forward more swiftly.

In one development, DuPont Displays have acquired Uniax Corporation of California. Other companies are active as well. In an alliance, Covion Organic Semiconductors GmbH from Frankfurt have linked up with eMagin Corp in New York. In this alliance Covion will provide the display technology for use in eMagin's current and future display products. This alliance is in turn partnering IBM to further develop OLED-on-silicon technology for use in a number of advanced display based applications.

In view of the level of work being undertaken, it can be seen that the industry is taking this new development very seriously, and soon OLED displays should start to appear in products on the market in large quantities.



# SIMPLE METRONOME

OWEN BISHOP

Project 6



This short collection of projects, some useful, some instructive and some amusing, can be made for around the ten pounds mark. The estimated cost does not include an enclosure. All of the projects are built on stripboard, and most have been designed to fit on to boards of standard dimensions. All of the projects are battery-powered, so are safe to build. In a few cases in which, by its nature, the project is to be run for long periods, power may be provided by an inexpensive mains adaptor. Again, the cost of such a unit is not included.

AS WELL as its obvious benefit to musicians (aspiring or arrived), this project can be used as a pacer by those busy with aerobics or other on-the-spot exercises. Its display consists of a row of light-emitting diodes (l.e.d.s). These are flashed one at a time, in order from left to right and repeating continuously.

A rotary switch selects the number of l.e.d.s flashed, which is equal to the number of beats in a bar. It allows the user to choose between 2/4, 3/4 and 4/4 time signatures:

1, 2, 1, 2, 1, 2, ...  
1, 2, 3, 1, 2, 3, 1, 2, 3, ...  
1, 2, 3, 4, 1, 2, 3, 4, 1, 2, 3, 4, ...

Another common time signature is 6/8 but, as the fourth note in each bar is often slightly accented, this can be obtained by using the 3/4 setting and doubling the tempo. The Tempo (Rate) is set by a variable resistor (potentiometer) and covers the range from *Largo* to *Presto*.

The Simple Metronome also has an audio output. This is provided by a piezoelectric sounder which emits a short beep at the beginning of each bar, that is, on the count of "one", which is when the left-most l.e.d. comes on.

## HOW IT WORKS

The full circuit diagram for the Simple Metronome is shown in Fig.1. The basic tempo is provided by timer IC1. This i.c. is a dual version of the well-known 555 timer. The other timer within IC1 is used to switch on the piezoelectric sounder WD1 when triggered.

The timer that controls tempo is wired as an astable multivibrator, which means that it generates a continuous series of pulses at a definite rate. Its frequency is controlled by the setting of Rate control VR1.

With the values shown in Fig.1, the frequency of the astable is variable from just over 1Hz up to 6Hz. A polyester capacitor is used for C4 because the capacitance of

this type does not vary with age and with use, as does that of the electrolytic type.

The output signal at pin 9 from the astable goes to the clock input (pin 14) of a divide-by-eight counter, IC2. The counter is incremented on the rising edge of each pulse. It has eight outputs, of which one goes to logic high at each count. The others remain at logic low.

For the counter to run, its reset input (pin 15) must be held low. A brief high level on the reset input triggers the counter to reset to zero.

As counting proceeds, the outputs would normally go high in order from 0 to 7, repeating. However, we use only the first five outputs in this circuit. For example, if we set Beat switch S2a for four beats to the bar, IC2 outputs 0, 1, 2 and 3 go high in that order. Then, when output 4 goes high, the high level is fed through S2 to the reset pin (IC2 pin 15).

Thus, as soon as output 4 (which would be a count of 5) goes high, the counter is

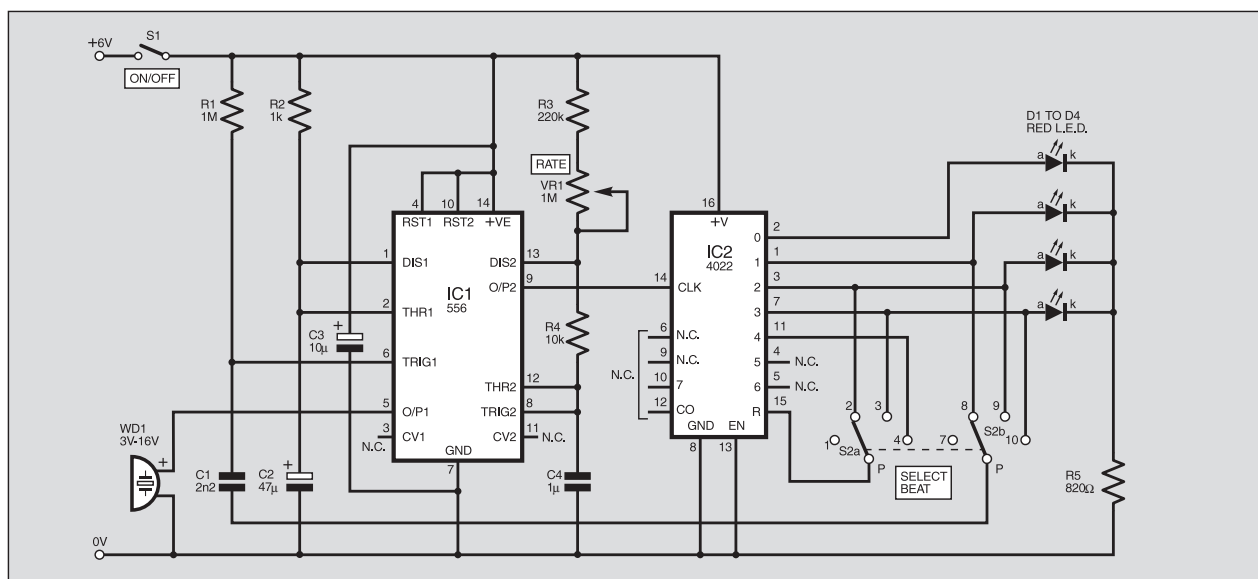


Fig.1. Complete circuit diagram for the Simple Metronome.

reset to zero. This takes only a few milliseconds, so it appears that the counter goes straight from count 4 to count 0. Similarly, we can use S2a to select outputs 3 and 2 to make the counter reset on the counts of 4 and 3 for 3/4 and 2/4 times.

## AUDIO COUNT

The audio bleep, count one, is produced by piezoelectric sounder WD1 that normally produces a high-pitched tone when it is switched on. To make the short "bleep", we use the second timer within IC1, wired as a monostable multivibrator.

With the values chosen for resistor R2 and capacitor C2, the monostable delivers a single high pulse of 0.05s duration every time its trigger input (pin 6) is made low. Note that we need a low-going input to trigger the timer (compare this to resetting, which requires a high input).

To make the "bleeps" coincide with the first count of each sequence, we need to trigger the timer as the l.e.d. goes out in the final count of each sequence. If there are four beats to the bar, for example, the monostable is triggered when the count of three ends.

The required connections are made by switch S2b. The pole (p) or wiper of S2b is connected through a capacitor (C1) to the trigger pin (pin 6) of IC1. This input is normally held high by the pull-up resistor R1. A low-going level at the pole of S2b is

sufficient to pull the input voltage down below 2V for long enough to trigger the monostable.

When IC2 switches the l.e.d.s on or off, this alters the load on the supply and may cause voltage spikes that upset the action of the counter. To avoid these, capacitor C3 is connected across the supply rails.

## CONSTRUCTION

The Simple Metronome circuit is built on a 0.1 inch matrix rectangle of stripboard, having 29 copper strips by 39 holes.

The component layout, interwiring and details of breaks required in the copper tracks are shown in Fig.2.

The unit runs on 6V, which may be provided by four 1.5V dry cells in a battery box. Alternatively, use a 6V mains power supply adaptor. An inexpensive one supplying 100mA at 6V d.c. unregulated is adequate.

If you are intending to house this project in a case, there are three items that should be mounted on the case: the power On/Off switch S1, the variable potentiometer VR1, and the rotary selector switch S2.

## COMPONENTS

### Resistors

R1	1M
R2	1k
R3	220k
R4	10k
R5	820Ω

All 0.25W 5% carbon film or better.

### Potentiometer

VR1	1M rotary carbon, linear
-----	--------------------------

### Capacitors

C1	2n2 polyester film
C2	47μ elec. 16V, axial
C3	10μ elec. 16V, axial
C4	1μ polyester

### Semiconductors

D1 to D4	5mm red l.e.d. (other sizes or colours optional)
IC1	556 dual timer
IC2	4022 CMOS divide-by-8 counter, with 1-of-8 outputs

### Miscellaneous

S1	s.p.s.t. toggle switch
S2	2-pole 6-way rotary switch (see text)
WD1	single-tone piezoelectric sounder, 3V to 16V.

Stripboard 0.1 inch matrix, size 29 copper strips by 39 holes; 14-pin i.c. socket; 16-pin i.c. socket; battery holder, with 4 x 1.5V cells or unregulated mains adaptor, see text; 1mm solder terminal pins (10 off); pointer knobs for VR1 and S2; multistrand connecting wire; solder, etc.

Approx. Cost  
Guidance Only

**£10**

excluding case

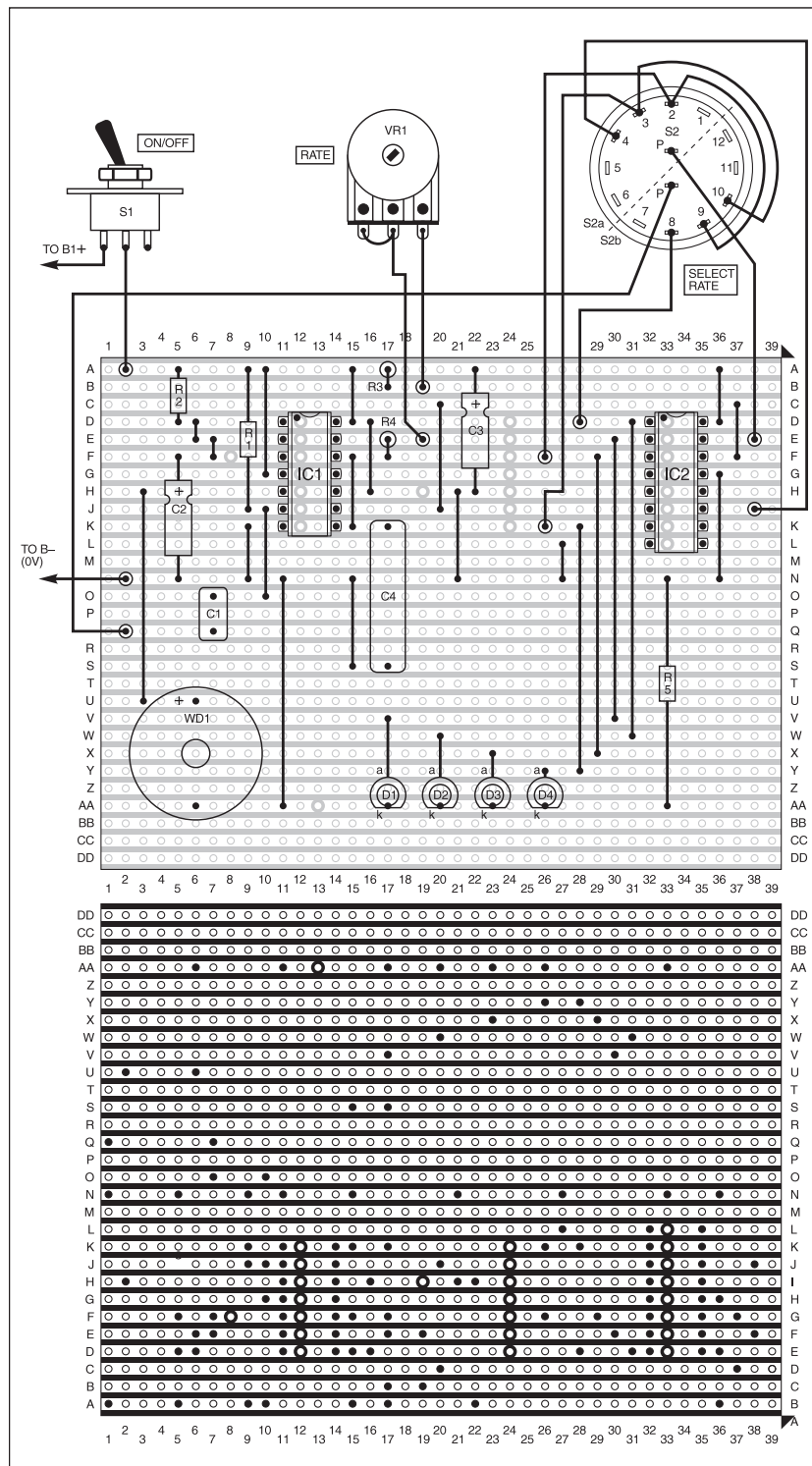
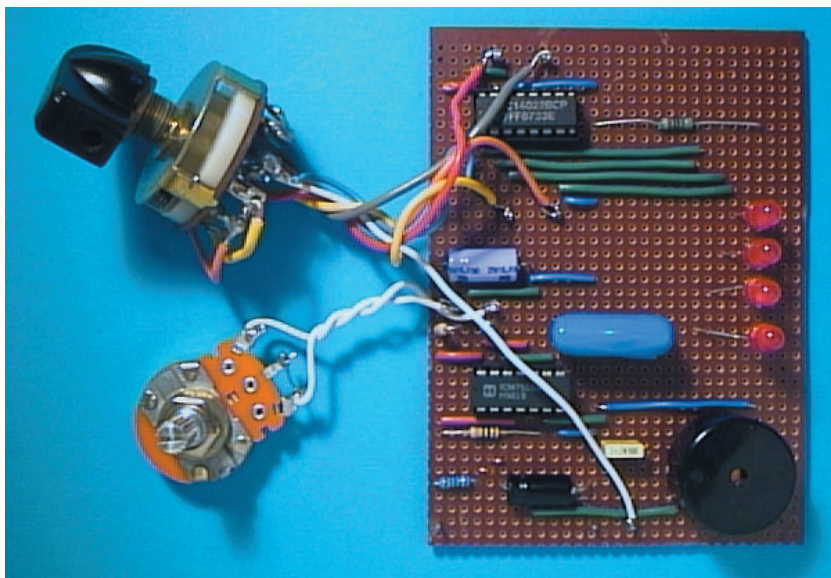


Fig.2. Simple Metronome stripboard component layout, interwiring to off-board components and details of breaks required in the copper tracks.



Component layout on the prototype circuit board. The finished unit can be mounted in a plastic box, with holes drilled for the l.e.d.s.

The rotary switch is relatively expensive and may put the cost of the project just above the £10 limit if you cannot find a cheap one. The component wiring diagram of Fig.2 shows a 2-pole 6-way switch, but a

3-pole 4-way switch or a 4-pole 3-way switch can be used equally well.

Alternatively, instead of a switch, you can solder a "flying lead" to each of the solder pins at points Q2 and E38 in Fig. 2.

Terminate each of the flying leads with a miniature crocodile clip. These clips are used for connecting to two of the terminal pins at D28, F26, K26 and J38, depending on the "beat" setting required.

## FINAL ASSEMBLY AND CHECKING

Following the component layout in Fig.2, first assemble the two circuits connected to IC1. When it is complete, temporarily connect the solder terminal pin at Q2 to the positive supply. If you then transfer the connection briefly to the 0V line, a short "bleep" should be heard.

Use a voltmeter or logic probe to monitor the output from the astable circuit at pin 9. Check that the frequency of the signal varies according to the setting of Beat control VR1.

Now complete construction of the project by adding the components associated with IC2 and the l.e.d.s. Wiring for the 2-pole 6-way Beat select rotary switch (S2) is also shown in Fig.2. Try to mount the l.e.d.s in as straight a row as possible and at the same height above the board. Check that the circuit now works as described earlier.

Finally, mount the off-board components (if the project is cased) and add labels for S2 and VR1. The latter may be calibrated in frequency or in musical terms. □

## SHOP TALK

with David Barrington

### How To Use Graphics L.C.D.s with PICs (Supplement)

The main point of consideration encountered when checking out components for the Graphics L.C.D. Demo Board, given in this month's special supplement, will be the graphics l.c.d. module. The author used a Powertip PG12864 graphics display purchased from RS Components, and is currently priced at £27.92 (excl VAT/p&p). This can be ordered through **Electromail** (☎ 01536 304555 or <http://rswww.com>), code 329-0329.

We understand that **Magenta** (☎ 01283 565435 or [www.magenta2000.co.uk](http://www.magenta2000.co.uk)) are hoping to supply graphic displays, with pin a connector at a reasonable cost in the near future. We suggest readers track their web site or give them a call for the latest news.

Contrary to the components list, you need an *unprogrammed* PIC16F877 chip; three lots of software will be installed and manipulated as you progress. A scan through our advertising pages should produce suppliers of PICs. Also, it follows that you must have a PIC programmer (such as the *PIC Toolkit Mk2* – May/June '99) to accompany this design.

The printed circuit board is available from the *EPE PCB Service*, code 288. The software is available on a 3.5-in. PC-compatible disk (*EPE Disk 4*) from the *EPE Editorial Office* for the sum of £3 each (UK), to cover admin. costs. (For overseas charges see page 149). It is also available free via the *EPE* web site: <http://ftp.epemag.wimborne.co.uk/pubs/PICS/graphicslcd>.

### Using The LM3914-6 L.E.D. Bargraph Drivers

Being popular devices, you should have no trouble ordering the National Semiconductors' LM3914 (linear), 3915 (log.) and 3916 (VU) family of l.e.d./bargraph display driver i.c.s, called for in the LM3914-6 feature, through your local component supplier.

It is a good idea to coat adjoining walls of the l.e.d.s with black paint to prevent "light spread" if making up your own bargraph display. It was found that 3mm dia. low current l.e.d.s gave the best results, probably due to less material thickness of the plastic body/shell.

The small, resistor-like, 4.7mH and 1mH r.f. chokes for the Relay Control unit link cable should be well stocked. The three printed circuit boards are available from the *EPE PCB Service* as a set, codes 289, 290, 291 (see page 149).

### Ice Alert

The specified Philips bead thermistor used in the *Ice Alert* project has a rating of 150kΩ at 25°C and about 535kΩ at 0°C. This device was purchased from **Maplin** (☎ 0870 264 6000 or [www.maplin.co.uk](http://www.maplin.co.uk)), code FX43W.

There is some latitude in the range of the thermistor used and it is appreciated that in some areas constructors will be limited in their choice. If you must use a different type, select one of the "negative

temperature coefficient" variety – that is, as the temperature rises the resistance falls – having a resistance of hundreds of kilohms at 0°C. Halve this figure and select the nearest fixed value resistor for R2.

The rest of the components for this unit should be readily available from our component advertisers. Do not forget, if you are installing the unit in a vehicle, the supply connections must be made using light-duty auto-type cable and with proper car-type connectors. Also, make sure you use nylon fixings when mounting the p.c.b. in its case.

The small printed circuit board is available from the *EPE PCB Service*, code 287 (see page 149). Finally, if installing the unit in a vehicle, check the car's manual to make sure it is safe to disconnect the battery before installation.

### PC Audio Power Meter

Several components called for in the *PC Audio Power Meter* could cause local sourcing problems. Most of the items used in the author's model came from **Maplin** (☎ 0870 264 6000 or [www.maplin.co.uk](http://www.maplin.co.uk)).

They supplied the 3W and 50W wirewound resistors. To order write/quote "W" then value (i.e. W0.1) for the 3W type and "X" then value (X3R9) for the 50W type. Suitable twin spring-loaded loud-speaker terminals are also stocked, code BW71P. They do not give an electrical rating for the terminal.

The Analog Devices AD7896AN 12-bit 8μs ADC chip and the ICL7660CPA switched capacitor voltage converter i.c. should be fairly widely stocked. Try **Cricklewood** (☎ 0181 452 0161) and **Maplin** (codes NP36P and NR54J respectively). The choice of case is left to individual taste. But it **must** be a metal type, due to heat generated within the case.

The software for this project is available on a 3.5-in. PC-compatible disk (*EPE Disk 4*) from the *EPE Editorial Office* for the sum of £3 each (UK), to cover admin costs (for overseas see page 149). It is also available free via the *EPE* web site:

<http://ftp.epemag.wimborne.co.uk/pubs/audiomet>.

### Simple Metronome

We do not expect any component buying problems to arise when shopping for parts for the *Simple Metronome*, this month's Top Tenner project.

The component wiring diagram shows a 2-pole 6-way rotary switch, but a 3-pole 4-way or 4-pole 3-way type can also be used in this circuit. Likewise with the single-tone piezoelectric buzzer, most of these sounders operate from a broad range of d.c. voltages and many of our component advertisers will be able to offer a suitable device.

## PLEASE TAKE NOTE

### Versatile Mic/Audio Preamplifier

May '00

In a recent issue we highlighted the problems of sourcing the SSM2166P mic. preamp chip for the *Versatile Mic/Audio Preamplifier* project and asked for help in finding some. We have just received news that **FML Electronics** (☎ 01677 425840) now have some in stock.



## £1 BARGAIN PACKS Selected Items

**CROCODILE CLIPS.** Small size, 10 each red and black. Order Ref: 116.

**PLASTIC HEADED CABLE CLIPS.** Nail in type, several sizes. Pack of 50. Order Ref: 123.

**30A PANEL MOUNTING TOGGLE SWITCH.** Double pole. Order Ref: 166.

**SUB MIN TOGGLE SWITCHES.** Pack of 3. Order Ref: 214.

**HIGH POWER 3in. SPEAKER** (11W 8ohm). Order Ref: 246.

**MEDIUM WAVE PERMEABILITY TUNER.** It's almost a complete radio with circuit. Order Ref: 247.

**HEATING ELEMENT.** Mains voltage 100W, brass encased. Order Ref: 8.

**MAINS MOTOR** with gearbox giving 1 rev per 24 hours. Order Ref: 89.

**ROUND POINTER KNOBS** for flatted 1/4in. spindles. Pack of 10. Order Ref: 295.

**CERAMIC WAVE CHANGE SWITCH.** 12-pole, 3-way with 1/4in. spindle. Order Ref: 303.

**REVERSING SWITCH.** 20A double pole or 40A single pole. Order Ref: 343.

**LUMINOUS PUSH-ON PUSH-OFF SWITCHES.** Pack of 3. Order Ref: 373.

**SLIDE SWITCHES.** Single pole changeover. Pack of 10. Order Ref: 1053.

**PAXOLIN PANEL.** Approximately 12in. x 12in. Order Ref: 1033.

**CLOCKWORK MOTOR.** Suitable for up to 6 hours. Order Ref: 1038.

**TRANSISTOR DRIVER TRANSFORMER.** Maker's ref. no. LT44, impedance ratio 20k ohm to 1k ohm, centre tapped, 50p. Order Ref: 1/23R4.

**HIGH CURRENT RELAY.** 12V D.C. or 24V A.C., operates changeover contacts. Order Ref: 1026.

**2-CORE CURLY LEAD.** 5A, 2m. Order Ref: 846.

**3 CHANGEOVER RELAY.** 6V A.C., 3V D.C. Order Ref: 859.

**3 CONTACT MICRO SWITCHES,** operated with slightest touch. Pack of 2. Order Ref: 861.

**HIVAC NUMICATOR TUBE.** Hivac ref XN3. Order Ref: 865.

**2IN. ROUND LOUDSPEAKERS.** 50Ω coil. Pack of 2. Order Ref: 908.

**5K POT,** standard size with DP switch, good length 1/4in. spindle, pack of 2. Order Ref: 11R24.

**13A PLUG,** fully legal with insulated legs, pack of 3. Order Ref: GR19.

**OPTO SWITCH** on p.c.b., size 2in. x 1in., pack of 2. Order Ref: GR21.

**1000W FIRE SPIRALS.** In addition to repairing fires, these are useful for making high current resistors. Price 4 for £1. Order Ref: 223.

**BRASS ENCASED ELEMENT.** Mains working, 80W standard replacement in some fridges but very useful for other heating purposes. Price £1 each. Order Ref: 8.

**PEA LAMPS,** only 4mm but 14V at 0.04A, wire ended, pack of 4. Order Ref: 7RC28.

**HIGH AMP THYRISTOR,** normal 2 contacts from top, heavy threaded fixing underneath, think amperage to be at least 25A, pack of 2. Order Ref: 7FC43.

**BRIDGE RECTIFIER,** ideal for 12V to 24V charger at 5A, pack of 2. Order Ref: 1070.

**TEST PRODS FOR MULTIMETER** with 4mm sockets. Good length very flexible lead. Order Ref: D86.

**LUMINOUS ROCKER SWITCH,** approximately 30mm square, pack of 2. Order Ref: D64.

**MES LAMP HOLDERS,** slide onto 1/4in. tag, pack of 10. Order Ref: 1054.

**HALL EFFECT DEVICES,** mounted on small heatsink, pack of 2. Order Ref: 1022.

**12V POLARISED RELAY,** 2 changeover contacts. Order Ref: 1032.

**PROJECT CASE,** 95mm x 66mm x 23mm with removable lid held by 4 screws, pack of 2. Order Ref: 876.

**LARGE MICRO SWITCHES,** 20mm x 6mm x 10mm, changeover contacts, pack of 2. Order Ref: 826.

**PIEZO ELECTRIC SOUNDER,** also operates efficiently as a microphone. Approximately 30mm diameter, easily mountable, 2 for £1. Order Ref: 1084.

**LIQUID CRYSTAL DISPLAY** on p.c.b. with ICs etc. to drive it to give 2 rows of 8 characters, price £1. Order Ref: 1085.

## THIS MONTH'S SPECIAL

IT IS A DIGITAL MULTITESTER, complete with backrest to stand it and hands-free test prod holder. This tester measures d.c. volts up to 1,000 and a.c. volts up to 750; d.c. current up to 10A and resistance up to 2 megs. Also tests transistors and diodes and has an internal buzzer for continuity tests. Comes complete with test prods, battery and instructions. Price £6.99. Order Ref: 7P29.



**1mA PANEL METER.** Approximately 80mm x 55mm, front engraved 0-100. Price £1.50 each. Order Ref: 1/16R2.

**VERY THIN DRILLS.** 12 assorted sizes vary between 0.6mm and 1.6mm. Price £1. Order Ref: 128.

**EVEN THINNER DRILLS.** 12 that vary between 0.1mm and 0.5mm. Price £1. Order Ref: 129.

**BT PLUG WITH TWIN SOCKET.** Enables you to plug 2 telephones into the one socket for all normal BT plugs. Price £1.50. Order Ref: 1.5P50.

**D.C. MOTOR WITH GEARBOX.** Size 60mm long, 30mm diameter. Very powerful, operates off any voltage between 6V and 24V D.C. Speed at 6V is 200 rpm, speed controller available. Special price £3 each. Order Ref: 3P108.

**FLASHING BEACON.** Ideal for putting on a van, a tractor or any vehicle that should always be seen. Uses a Xenon tube and has an amber coloured dome. Separate fixing base is included so unit can be put away if desirable. Price £5. Order Ref: 5P267.

**MOST USEFUL POWER SUPPLY.** Rated at 9V 1A, this plugs into a 13A socket, is really nicely boxed. £2. Order Ref: 2P733.

**MOTOR SPEED CONTROLLER.** These are suitable for D.C. motors for voltages up to 12V and any power up to 1/6h.p. They reduce the speed by intermittent full voltage pulses so there should be no loss of power. In kit form these are £12. Order Ref: 12P34. Or made up and tested, £20. Order Ref: 20P39.

**BT TELEPHONE EXTENSION WIRE.** This is proper heavy duty cable for running around the skirting board when you want to make a permanent extension. 4 cores properly colour coded, 25m length. Only £1. Order Ref: 1067.

**LARGE TYPE MICROSWITCH** with 2in. lever, changeover contacts rated at 15A at 250V, 2 for £1. Order Ref: 1/2R7.

**BALANCE ASSEMBLY KITS.** Japanese made, when assembled ideal for chemical experiments, complete with tweezers and 6 weights 0.5 to 5 grams. Price £2. Order Ref: 2P44.

**CYCLE LAMP BARGAIN.** You can have 100 6V 0.5A MES bulbs for just £2.50 or 1,000 for £20. They are beautifully made, slightly larger than the standard 6.3V pilot bulb so they would be ideal for making displays for night lights and similar applications.

**DOORBELL PSU.** This has AC voltage output so is ideal for operating most doorbells. The unit is totally enclosed so perfectly safe and it plugs into a 13A socket. Price only £1. Order Ref: 1/30R1.

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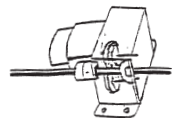
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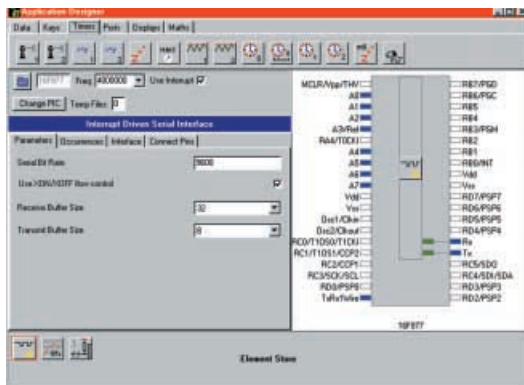
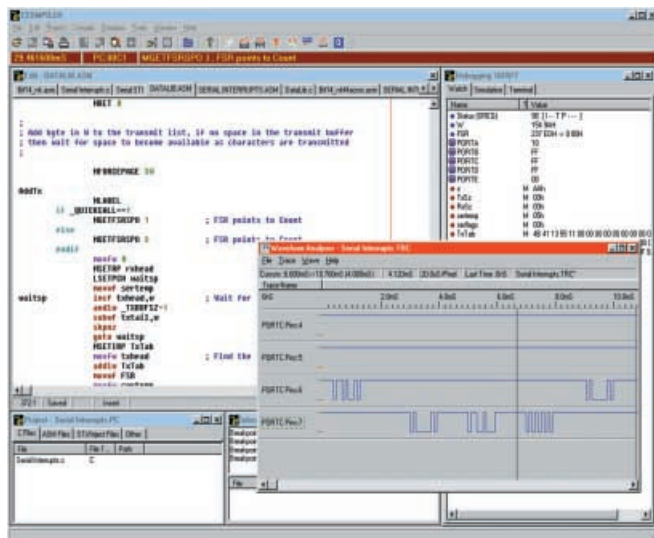
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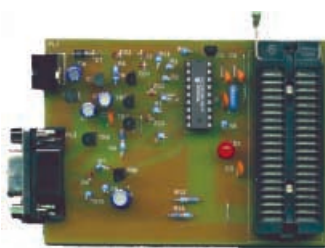


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## Charge Pumps

VOLTAGE multipliers require an a.c. input, but it is also possible to use transistors or logic gates to control the capacitor charging and switching required for voltage "multiplication". Such circuits are called **charge pumps** and are, in fact, available as i.c.s, including the TPS60100 series from Texas Instruments. These chips are typically used for low voltage conversion (e.g. +1.8V to +5V), or negative supply generation (e.g. -5V from +5V) and commonly they have fixed output voltages.

For non-standard conversions and higher output voltages, a charge pump can be built from basic components – an example is outlined in Fig.1. In this circuit CMOS inverters are used to drive a network of capacitors and diodes to achieve (ideally) a quadrupling of the input voltage. The circuit is best understood by remembering that CMOS inverters consist of two transistors in a "push-pull" configuration such that at a given time only one transistor is switched on.

This is basically equivalent to two complementary switches, as illustrated in Fig.2,

which in turn can be considered as a two-way switch connecting the output to either ground (0V) or the positive supply alternately. Re-drawing Fig.1 in this form results in the circuit of Fig.3, from which we can see that one end of each capacitor is alternately connected to ground and +V<sub>DD</sub>.

## How It Works

In the following description of how this circuit works we'll ignore diode voltage drops to keep things simple. In practice they will mean that the actual voltages are not quite the exact multiples of the input.

To begin with let's consider capacitor C1. When the input clock is high (+V<sub>DD</sub>), this is inverted by switch S1 which connects one end of C1 to ground (0V), so C1 charges up to +V<sub>DD</sub>.

When the clock goes low again, it is inverted by S1, so the negatively charged plate of C1 is now at +V<sub>DD</sub>. The voltage that currently exists across C1's plates means that the total voltage at point A is pushed up to +2 × V<sub>DD</sub>, i.e. a combination of +V<sub>DD</sub> from the supply, and +V<sub>DD</sub> from C1.

While point A is at +2 V<sub>DD</sub> (i.e. when the clock is low), one end of capacitor C2 is connected to ground via switch S2 and the other end to point B. So C2 will charge to +2 × V<sub>DD</sub> with current flowing from Point A via D2. During this time D1 is reverse biased.

The process of charging C2 will actually discharge C1 to some extent. Thus it will actually take several clock cycles for C2 to charge to the point that it has +2 × V<sub>DD</sub> across it. When the clock goes high again, C1 will again charge to +V<sub>DD</sub> via D1, replenishing the charge it pumped into C2.

Meanwhile (with clock high), the negative side of C2 will be connected to +V<sub>DD</sub> so the voltage at point B will be +3 × V<sub>DD</sub> and capacitor C3 will charge to this voltage via diode D3, just as C2 charged to +2 × V<sub>DD</sub> via D2. In a similar way C3 will charge to +4 × V<sub>DD</sub>.

The voltage at point A switches between V<sub>DD</sub> and +2 × V<sub>DD</sub>, the voltage at B switches between +3 × V<sub>DD</sub> and +2 × V<sub>DD</sub>, and the voltage at point C switches between +3 × V<sub>DD</sub> and +4 × V<sub>DD</sub> as the clock switches high to low. In order to get a d.c. output, diode D4 is used to charge capacitor C4 to +4 × V<sub>DD</sub> from C3.

Negative output voltages can be obtained by reversing the diodes in the chain and connecting the V<sub>in</sub> point to ground. In practice the output voltages obtained will be less than those described due to diode drops and other "losses" in the circuit.

## Upstaged Multipliers

This circuit (Fig.1) can be extended by adding further stages so you can multiply the input voltage by quite a large amount (10 or more stages are quite feasible). The current available from the output depends on the current available from the inverters and on the values of the capacitors. If you use 4049s this will be a couple of milliamperes. You can wire

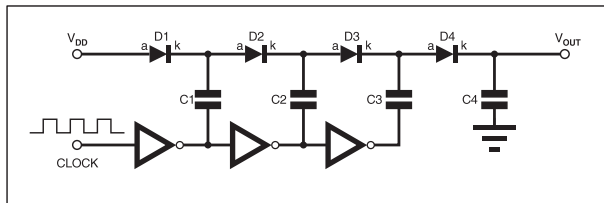


Fig.1. Example circuit of a CMOS inverter-based charge pump d.c. voltage multiplier. Note V<sub>OUT</sub> is approx. four times V<sub>IN</sub>.

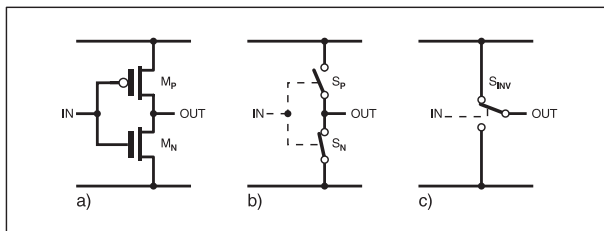


Fig.2. The CMOS inverter (a) can be viewed as two voltage controlled switches such that when one is on the other is switched off (b), this in turn can be viewed as a changeover switch connecting the output to either +V or 0V depending on the input voltage (c).

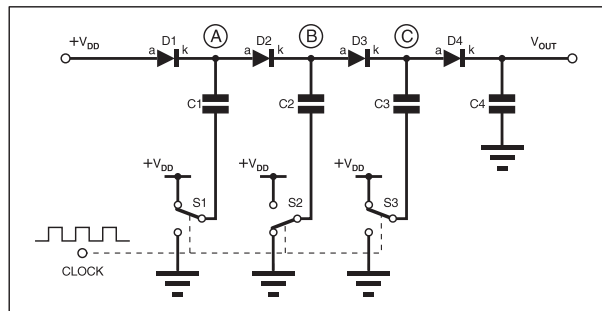


Fig.3. The multiplier circuit of Fig.1 re-drawn to show the switching action of the CMOS inverters in a voltage multiplier.



CMOS inverters in parallel to increase the current capacity.

For a practical circuit you can also consider using an inverter to make a simple CMOS oscillator to provide the clock for the pump chain; the frequency is not particularly critical and should typically be 50kHz to 100kHz. The capacitor values in the charge pump circuit are also not crucial at this frequency, 10nF to 100nF should be suitable.

When constructing these circuits you *must* take note of the voltage ratings of the capacitors – for example do not use a 25V rated capacitor for an output at 48V! The output voltage will have some ripple, so the use of a larger output capacitor will reduce the ripple voltage. The diodes should be switching diodes such as 1N4148, rectifier diodes (e.g. 1N4001) are unsuitable.

## Making Headroom

One of the problems with this circuit is poor load regulation – the output voltage will drop as the load current increases. This can be overcome using a Zener diode at the output or by using a simple feedback circuit as shown in Fig.4.

In this circuit the final stage of the pump uses a *tristate* device to allow the pump to be switched off or isolated by the comparator when the output reaches a certain voltage. This voltage should be set to be somewhat lower than the “open circuit” voltage with no load and the pump on all the time. This gives the circuit some “headroom” to cope with load variations. Notice that we incorporated a clock circuit as well.

Under very light load conditions the final stage in Fig.4 will be off most of the time,

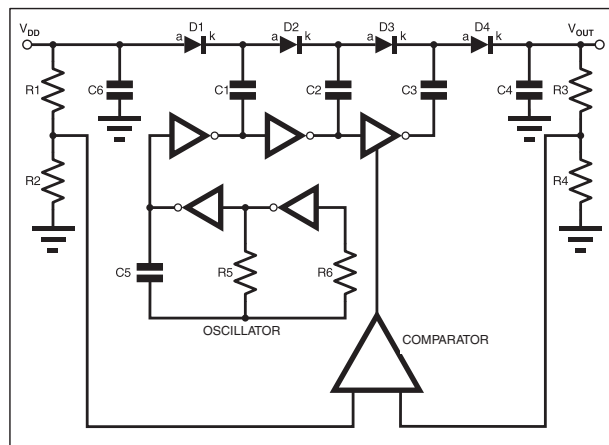


Fig.4. Charge pump circuit with the output regulated to be a fixed multiple of  $V_{IN}$ .

with the pump switching on now and then to replenish the charge in the output capacitor. As the load current increases the output capacitor will discharge more rapidly and the pump will have to be on more often to keep the output voltage at the required level. If the load increases further still, the pump will have to be on all the time, after which regulation will be lost and the output voltage will drop as the load increases, just as it will do with the original circuit.

The values of resistors R1 to R4 are chosen so that the same voltage appears at the output of both potential dividers. For example if  $V_{DD}$  was +9V and R1 and R2 were equal, they would produce a +4.5V reference level. If the desired output was 48V – which is the value mentioned in the question last month – R3 and R4 would be selected to give +4.5V

too. The comparator would then switch on the output stage of the pump when the output voltage fell below 48V (i.e. the comparator input fell below 4.5V).

Note that the need for “headroom” for the regulated circuit will mean the effective “multiplication factor” for the input to output voltage will be reduced in this version of the circuit and this should be borne in mind when deciding how many stages are required. *I.M.B.*

## Darlington Drivers

*I am going to be using a ULN2803A Darlington array in a forthcoming project. I am planning initially to use only four of the transistors, so I would like to know if the remaining ones should be left open circuit or connected to  $V_{CC}$ .* **John Pickard**, by E-mail.

These devices are useful general-purpose buffers containing eight Darlington transistor drivers which enable higher power (and higher voltage) loads to be driven directly by low voltage logic circuits. Each buffer is rated at 500mA continuous output *sink* current, and you can parallel the outputs to handle even higher loads: they are ideal for lamps, i.e.d. arrays, stepper motors etc.

The ULN28xx range pinouts are shown in Fig.5. They have open-collector outputs, with built-in clamping diodes for back-e.m.f. protection – see how all the diode cathodes (k) are commoned to pin 10. A dual-in-line package can handle as much as 300 watts of load, provided that the buffers are strobed at a suitable duty cycle.

I checked the Allegro data book for clues, and it shows that each buffer has internal resistors, presumably to make the buffers 5V TTL/CMOS compatible. The 2803 uses a 2k7 resistor on each base, plus a 10k divider biasing it to ground (0V).

On that basis, I would say that it is safe to leave device inputs floating. You can also download a data sheet from Allegro at [www.allegromicro.com](http://www.allegromicro.com). **ARW.**

## More on Multimeters

Following up on the item on using multimeters to test transistors (*Circuit Surgery* October

2000), my thanks to **Peter Hemsley** who writes by E-mail:

*The polarity of the positive and negative leads of an analogue meter (i.e. positive comes out of the negative terminal) are not as expected due to the simple circuitry employed and no-one considers it necessary to have extra switching to correct the polarity. The circuit consists of a current meter, a variable resistance (to set the zero) and a battery all in series, so the negative connection of the meter is connected to the negative test lead, and the positive test lead is connected to the negative of the battery. Hence the reversal of polarity. Digital multimeters use a completely different method, the test leads are effectively connected to the input of the DVM i.e. measuring voltage.*

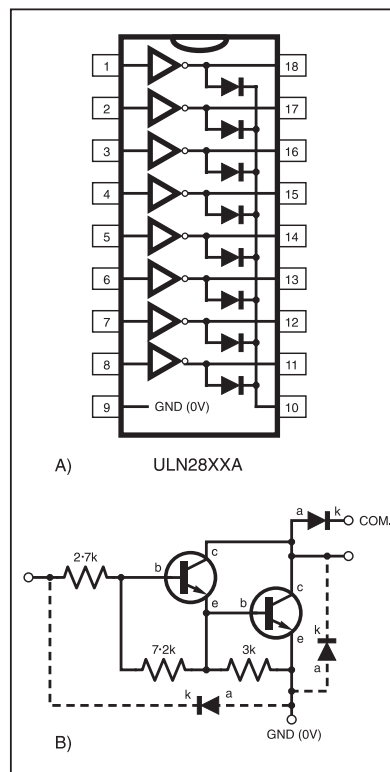


Fig.5. (a) Pinout details for the ULN28XX Darlington array and (b) basic circuit.

*One method of producing a voltage proportional to resistance is to pass a constant current through the resistor being measured, but this has the disadvantage that the current source needs to be stable and not suffer from drift. The usual way of measuring resistance is to use the ratio-metric method, where the resistor being measured is connected in series with a reference resistor across a voltage source (usually a few hundred millivolts).*

*The resistor under test is connected to the measuring input and the reference resistor to the reference input of the DVM i.e., the resulting reading is then the ratio of the voltage across the unknown and the reference resistor. Thus the accuracy of the reading is determined by only the accuracy of the reference resistor.*

Thank you for the extra information. For reference Fig. 6 is the internal circuit of a typical moving coil resistance meter. Notice how the battery's negative terminal is indeed connected to the positive test socket. **ARW.**

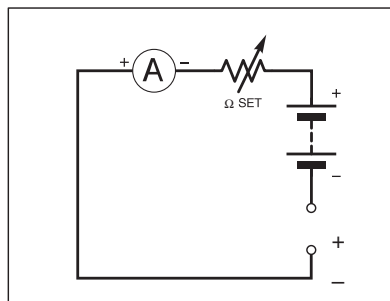


Fig.6. Internal view of an analogue multimeter set for resistance measurement. The positive terminal is connected to the battery negative pole.

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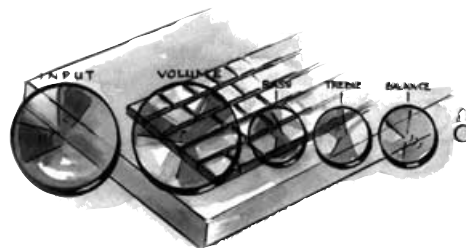
esm2



# Constructional Project

# PC AUDIO POWER METER

ROBERT PENFOLD



## PC computer interface for measuring power output from audio amplifiers

**T**HIS project is the latest in the occasional series of PC-based test equipment. Previous units were based on circuits from the *Interface* series of articles. This device is based on an analogue-to-digital converter (ADC) featured in the series, but it is otherwise original.

It enables a PC to measure power, and it is primarily intended for use with audio power amplifiers. However, the interface uses d.c. coupling and it could probably be modified for use in some d.c. power measuring applications.

When used for audio power measurement it provides an 8 $\Omega$  dummy load, and shows the peak power and voltage delivered to the load. It also has a virtual panel meter that shows the r.m.s. power level when using sine wave test signals. With sine wave test signals the r.m.s. power level is easily calculated, since it is exactly half the peak power level.

The 12-bit ADC is scaled to read voltages from 0V to 40.95V. With 40 volts into an 8 $\Omega$  load it equates to 200 watts ( $40 \times 40 = 1600$ ,  $1600/8 = 200$ ), or 100 watts r.m.s. when using a sine wave test signal. The 8 $\Omega$  dummy load can handle a little over 100 watts r.m.s. provided it is equipped with adequate heatsinking.

The circuit connects to the printer port of the host PC, and the port does not need to be a bidirectional type. The power meter program is written in *Visual Basic 6*, and it requires Windows 95, 98 or ME to run. Note that it will *not* work with other versions of Windows. Visual Basic 6 produces programs that are incompatible

with 16-bit versions of Windows such as version 3.1. Windows NT and 2000 do not permit the form of direct port access, which is essential to the operation of this software.

### DUMMY LOAD

The block diagram of Fig.1 shows the system used in the PC Audio Power Meter. The input signal is connected to a dummy load, which is simply an 8 $\Omega$  resistor that takes the place of a loudspeaker. This

on the assumption of an 8 $\Omega$  load impedance could have huge errors if the impedance of the loudspeaker was actually more like 6 $\Omega$  or 12 $\Omega$  at the test frequency.

Another problem in using a loudspeaker as the load is that the load would not be purely resistive. There would also be elements of capacitance and inductance, and this slightly complicates matters. With a load that is pure resistance the output current is precisely in-phase with the output voltage.

### PEAK PRACTICE

In order to calculate the peak output power it is merely necessary to measure the peak output voltage. From this voltage and the load resistance it is possible to calculate the output power using the method used previously (square the voltage and divide this figure by the load resistance).

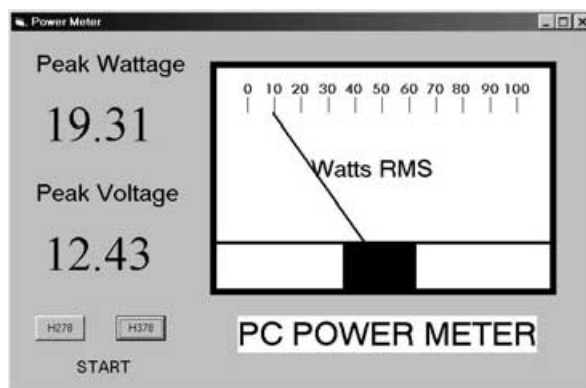
Things are more complicated when using a loudspeaker as the load. Because the precise impedance is an unknown quantity, the output voltage and current must both be measured. Simply multiplying the peak voltage by the peak current may not give an accurate figure for peak power, because maximum current might not coincide with maximum voltage.

With capacitance and inductance in the load there are so-called imaginary currents to deal with, as well as the real currents. The point to remember here is that current can flow into and out of theoretically perfect capacitors and inductors, but they do not dissipate any power. To be sure of accurate results the output current and voltage must be continuously sampled and processed by a multiplier circuit to produce a power reading that is always accurate. The peak reading from the multiplier will truly reflect the peak output power from the amplifier.

### SYSTEM OPERATION

To avoid complications and ensure consistent test conditions, most audio power amplifier testing is undertaken using a dummy load resistor. For the reasons outlined previously, it is essential to the operation of this power measuring system that the load is a resistor and not a loudspeaker.

The signal fed to the load is also fed to an attenuator that is used to give the correct



Virtual screen display of the PC Power Meter.

avoids having unduly loud test tones coming from a loudspeaker used as the load, and it also simplifies measurements.

The main problem with using a loudspeaker as the load is that its actual impedance can vary considerably from its nominal figure of 8 $\Omega$ . The actual impedance tends to vary significantly with changes in the input frequency. Measurements made

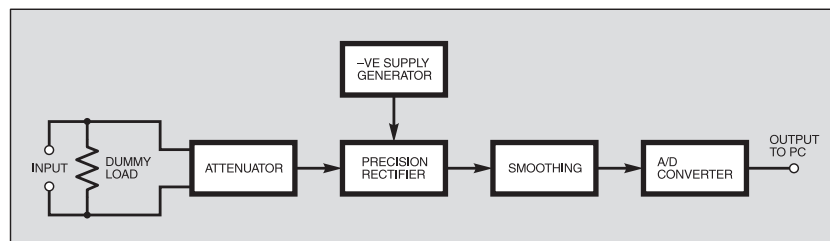


Fig.1. Block diagram for the PC Audio Power Meter system.

scaling. The ADC has a full-scale reading of 4095, which is achieved at an input potential of 5V. By reducing the input potential by a ratio of a little over 7-to-1 the full-scale input voltage of the circuit as a whole is increased to the required figure of 40.95. The attenuation is adjustable so that the unit can be calibrated against an accurate reference voltage.

With symmetrical waveforms it is only necessary to measure the peak positive or negative input voltage, but not both as they will be the same. With asymmetric waveforms there can be a substantial difference between the peak positive and negative voltages, making it necessary to measure both in order to guarantee accurate results.

In this unit the output of the attenuator is fed to a precision full-wave rectifier so that both sets of half-cycles are measured. The rectifier circuit requires a negative supply, and this is derived from the 9V battery via a simple switch-mode circuit.

The output of the rectifier feeds a smoothing circuit that has a short attack time and a much longer decay period. The effect of this is very much like a peak-hold circuit, with a d.c. output voltage that is equal to the peak input potential.

Resistors R1 and R4 each take little more than one percent of the total power fed to the load, and a rating of two or three watts is therefore adequate for these.

The input attenuator consists of fixed resistor R5 and preset VR1. The latter enables the full-scale sensitivity to be adjusted so that the unit can be accurately calibrated.

IC1 is a dual operational amplifier and it is used in the precision rectifier. Simply feeding the signal through a diode does not give the desired result due to the non-linearity of all semiconductor diodes. An ordinary silicon diode requires a forward bias of about 0.6V before it will start to conduct significantly, and the forward resistance then plummets with only a small increase in the applied voltage.

This means that around 0.6V is needed before any output signal is produced, and



applies the feedback if the output goes negative. This gives what is virtually a standard voltage follower circuit, but the output signal, whatever its polarity, is boosted by about 0.6V.

On positive half cycles D3 feeds the output signal to the smoothing circuit. The voltage added at the output of IC1a by D1 counteracts the losses through D3, giving accurate half-wave rectification via IC1a and D3. IC1b operates as an inverting amplifier having unity voltage gain, and this inverts the output signal from IC1a. On

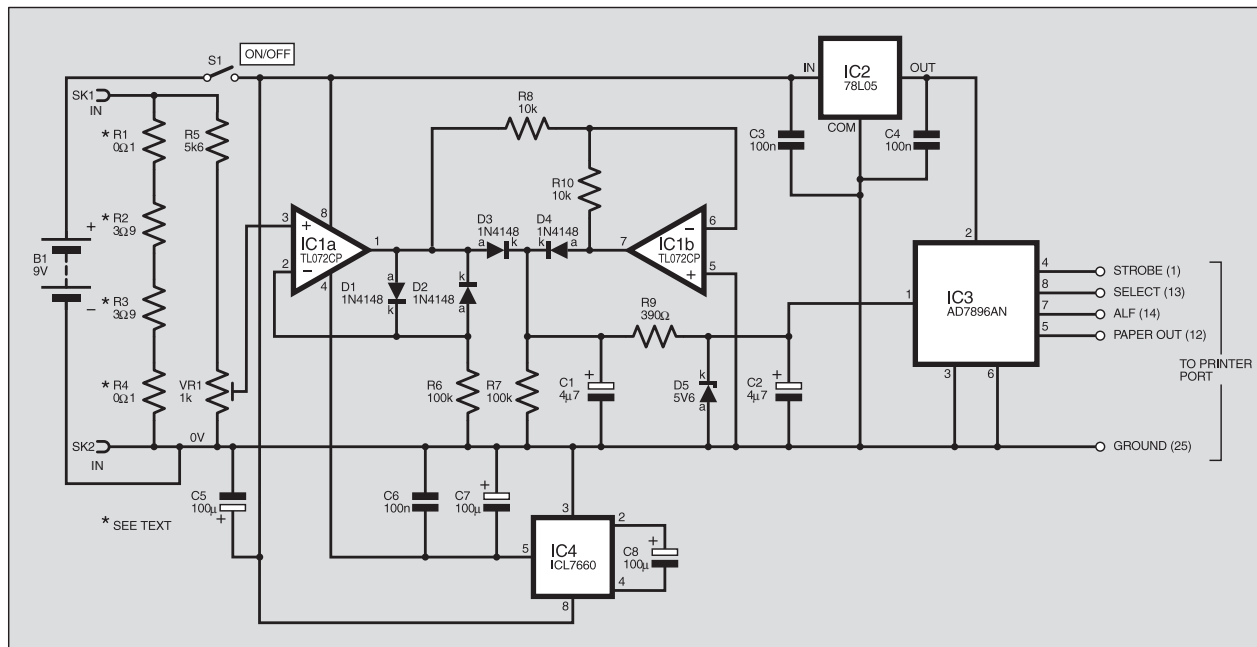


Fig.2. Complete circuit diagram for the PC Audio Power Meter. Note that resistors R1 to R4 must be high wattage types.

The ADC is a 12-bit type that uses serial interfacing to the PC. This enables 12-bit values to be read by way of just two input lines and two output types. Four of the printer port's handshake lines are adequate to provide the interfacing, making it unnecessary for the port to have bidirectional data lines.

## CIRCUIT OPERATION

The full circuit diagram for the PC Audio Power Meter appears in Fig.2. The required value for the dummy load is 8Ω, but this is not a "preferred" value. To make up the value of 8Ω, four resistors (R1 to R4) are connected in series. R2 and R3 provide most of the resistance and therefore have to dissipate most of the power. Accordingly, they have power ratings of 50 watts each.

at higher input potentials the output voltage is about 0.6V or so lower than it should be. There are diodes that offer lower forward voltage drops, but none give adequate performance where good linearity is required.

The standard solution to the problem is to include two diodes in the negative feedback circuit of a non-inverting amplifier. In this case the diodes are D1 and D2, and the amplifier is IC1a. At input potentials of less than about 0.6V there is no significant feedback through D1 and D2, which results in IC1a operating at its open loop voltage gain.

This gain is very high, so only a small input voltage is needed to send the output about 0.6V positive or negative. Diode D1 then starts to apply strong negative feedback if the output goes positive, or D2

negative input half cycles the output of IC1b therefore produces positive half cycles that are fed to the smoothing circuit via diode D4.

The negative voltage added at the output of IC1a by D2 produces a positive voltage at the output of IC1b. This voltage counteracts the voltage drop through D4, giving the required precision rectification. The combined output of D3 and D4 does, of course, provide full-wave rectification.

The smoothing circuit has the smoothing capacitance provided by C1 and C2 in parallel. The low source impedance of the rectifier circuit provides a fast attack time, but the high value of resistor R7 produces a much slower decay time.

The value of the smoothing capacitance has to be a compromise. A high value is needed in order to avoid jittery readings at

low frequencies, but also makes the unit slow to respond to a reduction in power level. The specified values for C1 and C2 represent something close to the minimum that should be used. Resistor R9 and diode D5 form a protection circuit that limits the input voltage to the converter to about -0.65 volts and +5.6 volts.

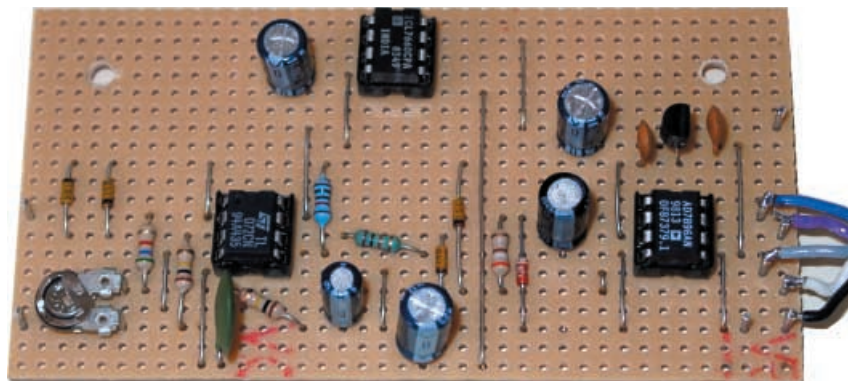
## DIGITAL CONVERSION

The ADC device, IC3, requires no discrete components. It requires a 5V supply, and this is derived from the 9V battery by way of a 5V monolithic voltage regulator (IC2). The full-scale input voltage of the converter is equal to the supply potential.

The chip interfaces to the PC via a simple four-wire serial system. The computer pulses pin 7 low to start a conversion and then monitors pin 8, which goes low when the conversion has been completed.

The first bit is then read from pin 5, a clock pulse is supplied to pin 4, the next bit is read from pin 5, another pulse is supplied to pin 4, and so on until 16 bits have been read. Note, though, that the first four bits are always at zero, and that the converter only provides 12 valid bits of data.

The negative supply for IC1 is provided by a simple switch-mode power supply based on IC4. This chip uses a d.p.d.t. electronic switch to first connect C8 to the 9V supply, and then connect it to the output. The switching is arranged so that a negative supply is produced on smoothing capacitor C7, and despite losses through IC4 the negative supply voltage is only marginally lower than the positive supply potential.



Component layout on the completed circuit board.

There is a slight imbalance in the supply potentials, but the difference is not large enough to be of any practical consequence. The current consumption of the entire circuit is about 8mA to 10mA. A PP3-size battery is just about adequate to supply this, but six AA size cells in a holder is a more practical choice if the unit will receive a great deal of use.

## CONSTRUCTION

Most of the components are assembled on a stripboard that measures 39 holes by 20 copper strips. This can conveniently be cut from a standard 39 by 29 or 39 by 39 stripboard. The component layout for the board and the underside view showing the breaks in the copper strips are given in Fig.3.

Construction follows along the usual lines with the two mounting holes being drilled in the board, the breaks being made in the strips, and then the components and link wires are fitted. The chips

used for IC3 and IC4 are MOS types that require the standard anti-static handling precautions.

In particular, they must be fitted in holders (sockets), and the use of a holder for IC1 is also recommended.

Do not fit the integrated circuits into the holders until all the wiring has been completed, and try to touch the pins as little as possible. Keep the integrated circuits away from any likely sources of strong static charges.

The link-wires are made from 22 or 24 s.w.g. tinned copper wire. It is a good idea to insulate the longer wires with p.v.c. sleeving to ensure that there are no accidental short-circuits. Fit single-sided solder pins at the points where connections to the off-board components such as SK1 and SK2 will be made. Generously tin the tops of the pins with solder, and it should then be easy to make reliable connections to them later on.

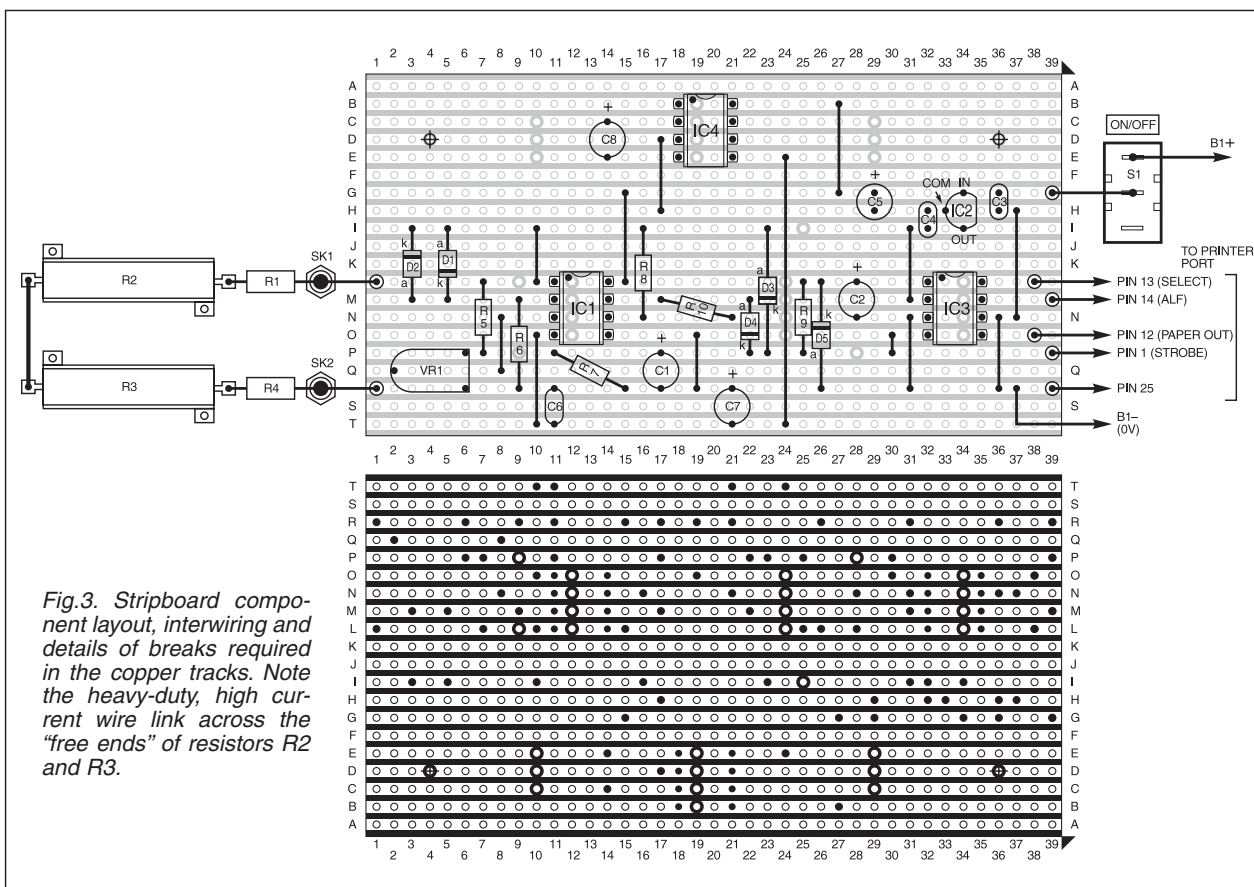


Fig.3. Stripboard component layout, interwiring and details of breaks required in the copper tracks. Note the heavy-duty, high current wire link across the "free ends" of resistors R2 and R3.



## ENCLOSURE

A metal case must be used for this project due to the substantial amount of heat generated by R2 and R3 when measuring high power levels. Note that these resistors can only be used continuously at their rated powers if they are fitted on substantial heatsinks rated at about 3°C per watt.

Provided the unit is housed in a reasonably large metal case having ventilation grilles the case should provide adequate heatsinking. If it is likely that the unit will be used with high output powers for long periods it is safer to fit the resistors onto large heatsinks.

The resistors, with or without heatsinks, are fitted on the base panel of the case near the rear of the unit, leaving sufficient space for the circuit board at the front (see photograph). It is advisable to use heatsink

compound to ensure that there is a good thermal contact between the resistors and the heatsink or chassis.

The fixings for the circuit board must include spacers about 6mm or more in length so that the connections on the underside of the board are kept well clear of the metal case.

Switch S1 is mounted at any convenient point on the front panel. SK1 and SK2 must be heavy-duty sockets that are capable of handling the high currents involved in this application. The types of connector that are normally used for loudspeaker outputs are the best choices, such as terminal posts or heavy-duty spring terminals.

Resistors R1 and R4 are connected between the sockets and the two high-power resistors, as shown in Fig.3. A wire to connect R2 and R3 is also needed, and is included in Fig.3, as is all the hard wiring. This wire carries high currents of up to about 5A r.m.s. and a fairly heavy gauge of wire must therefore be used. Ordinary hook-up wire is suitable for the connections from sockets SK1 and SK2 to the circuit board, since this is a low current connection.

## LINKING-UP

The easiest way to make the connections to the printer port of the PC is to hard wire one end of the cable to the circuit board, and to connect the other end to a 25-way male D-type connector. This type of connector is the standard type for the printer ports of desktop PCs. Virtually any 5-way cable is suitable, but about one metre of ribbon cable is probably the best choice.

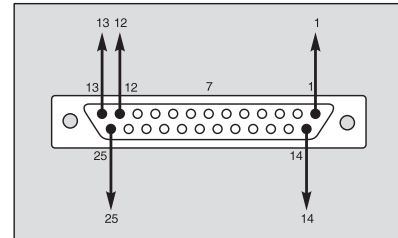


Fig.4. The five connections to the 25-way male D-connector.

The pin numbering and connections to the 25-way connector are shown in Fig.4, which shows the connector viewed from the rear (i.e. the side to which the connections are made). An exit slot for the cable must be filed in one side of the rear panel.

The alternative method is to wire the circuit board to a 25-way D-connector fitted on the rear panel. The interface is then connected to the PC via a suitable 25-way D-connector lead. This is in some ways the neater way of doing things, but is more difficult and expensive to implement. Also, great care has to be taken to ensure that all the connections are carried through correctly to the PC.

## CALIBRATION AND USE

Since the unit is d.c. coupled, the easiest calibration method is to feed the input from a bench power supply unit. An accurate multimeter is used to set a known output voltage, and preset VR1 is then adjusted to give the appropriate voltage reading

## COMPONENTS

### Resistors

R1, R4	0Ω21 3W 5% wirewound (2 off)
R2, R3	3Ω29 50W wirewound (2 off)
R5	5k6 0.25W 5% carbon film
R6, R7	100k 0.25W 5% carbon film (2 off)
R8, R10	10k 0.6W 1% metal film (2 off)
R9	390Ω 0.25W 5% carbon film

### Potentiometer

VR1	1k miniature preset, horizontal
-----	---------------------------------

See  
**SHOP**  
**TALK**  
page

### Capacitors

C1, C2	4μ7 radial elect. 50V (2 off)
C3, C4, C6	100n disc ceramic (3 off)
C5, C7, C8	100μ radial elect. 10V (3 off)

### Semiconductors

D1 to D4	1N4148 signal diode (4 off)
D5	5V6 400mW Zener diode
IC1	TL072CP dual op.amp
IC2	78L05 +5V 100mA voltage regulator
IC3	AD7896AN 12-bit ADC
IC4	ICL7660 voltage converter

### Miscellaneous

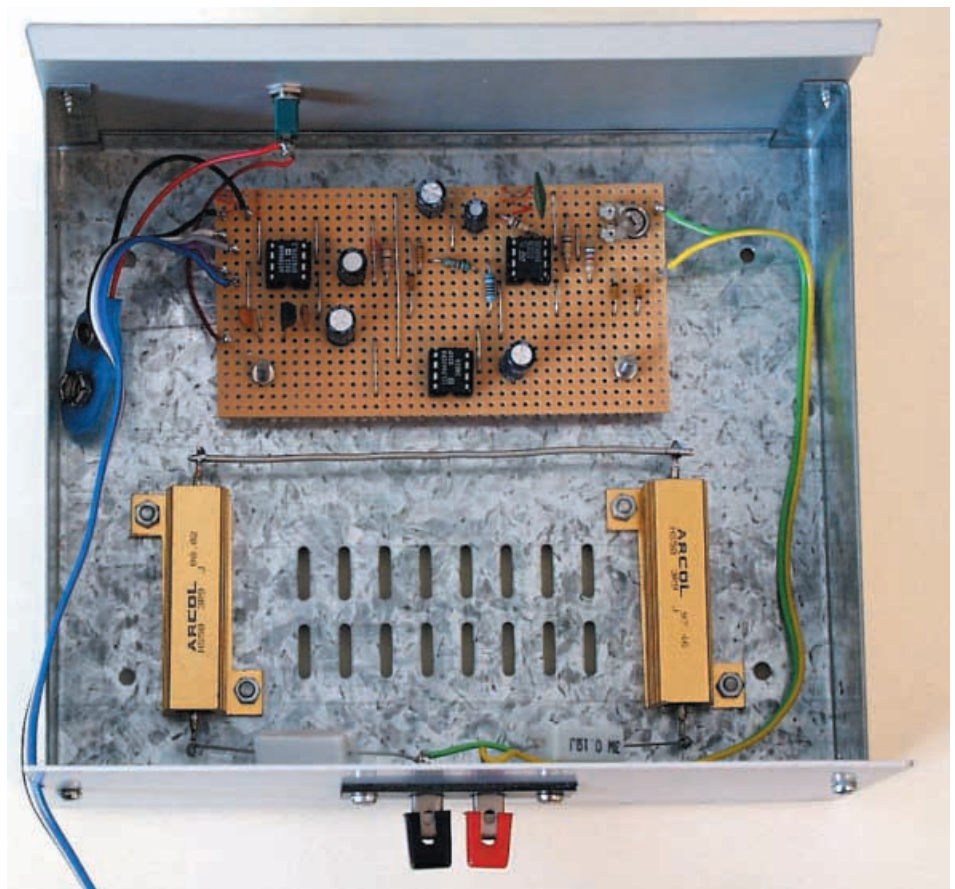
S1	s.p.s.t. min. toggle switch
B1	9V battery (PP3 type – see text)
SK1, SK2	spring terminals (see text)

Metal case, 175mm x 160mm x 85mm (approx); 0.1-inch matrix stripboard, 39 holes x 20 strips; 8-pin d.i.l. socket (3 off); battery connector; 25-pin male D-type connector and 5-way lead (see text); connecting wire; fixings; solder, etc.

Approx. Cost  
Guidance Only

**£27**

excluding case & batt.



General internal layout of components inside the metal case. The high power resistors (R2, R3) are bolted to the metal base panel, either side of the vent slots.

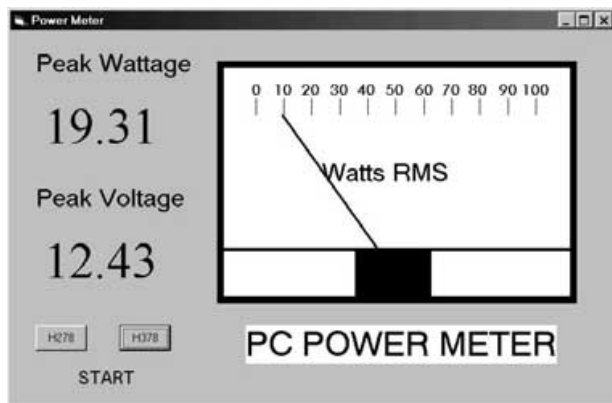


Fig.5. Screen dump of the PC Audio Power Meter in action.

from the on-screen voltage display. Bear in mind that the dummy load will give quite high current flows when using even quite low input voltages. If loading of the power supply is a problem, temporarily disconnect the dummy load while the unit is calibrated.

Also bear in mind that one input socket (SK2) connects to earth. If one output of the power supply is also earthed it is essential to connect the supply with the correct polarity or it will be short-circuited.

When testing most ready-made amplifiers it does not matter which way round the outputs are connected to the inputs of the power meter interface. Ready-made amplifiers usually have double insulation and no connection to the mains earth lead. It would clearly be prudent to check this point before connecting an amplifier to the interface. If one output is connected to the mains earth lead, then this output must connect to the earth rail of the interface, which will almost certainly be earthed via the PC.

Home constructed power amplifiers that are mains powered normally have one output connected to the mains earth, and it is then imperative that this output connects to the earth rail of the interface. Home built amplifiers that use the bridging technique usually have an earthed chassis, but neither output connected to earth. **Amplifiers of this type must not be used with this interface, and very high output currents would flow if they were connected to the unit.**

### FOUR-OHM LOAD

It is easy to modify the unit to provide a 4Ω load. The simplest method is to replace R1 and R2 with a shorting link, or to have a heavy duty switch connected across them so that the unit can be switched from 8Ω to 4Ω operation. Obviously this method halves the power rating of the dummy load to a little over 50 watts.

The alternative is to add another set of four resistors in parallel with the existing dummy load. These could be connected via a heavy-duty switch to permit switching between 4Ω and 8Ω operation. The advantage of this method is that the power rating of the dummy load is doubled when the extra resistors are used. Of course, a given input voltage produces double the current flow and power level when a 4Ω load is used. The digital display will then read equivalent r.m.s. power and not the peak power level.

### PROGRAM OPERATION

A screen dump of the program in operation is shown in Fig.5. Clicking on either of the buttons sets the printer port address range used and starts the program. Printer port 1 is normally at base address H378, and port 2 is usually at H278.

The digital readouts provide readings of peak power and voltage, and the analogue readout on a virtual panel meter gives the equivalent r.m.s. power value. *Note that the r.m.s. reading is only valid when using sinewave test signals with no serious clipping of the output signal.*

The routine that reads the converter and updates the displays is assigned to a timer. Initially the timer is disabled, but operating one of the command buttons assigns the appropriate values to the variables that store the port addresses and then enables the timer. The routine assigned to the timer starts by generating a pulse to start a conversion. A hold-off is then needed to allow time for the conversion to be completed.

This can be provided by monitoring the Busy output of the converter, which goes low when a conversion has been completed. This method was used for previous EPE designs that used the AD7896 converter chip, but it seems to result in the program tending to hang when used with some printer ports.

The Busy line is connected to the printer port so that this method can be tried by those who like to "do their own thing", but the use of a delay loop seems to be the

safer option. This is the method used here, and the delay subroutine is also used to lengthen all the control signals from the computer. This reduces the risk of problems with stray coupling in the connecting cable.

Next the data is clocked out, read bit by bit, and assembled into a 12-bit value. Dividing the value from the converter by 800 and 100 respectively provides the current and voltage readings. The software provides no current readout, but this value is available in the Current variable for anyone who wishes to use it in his or her own version.

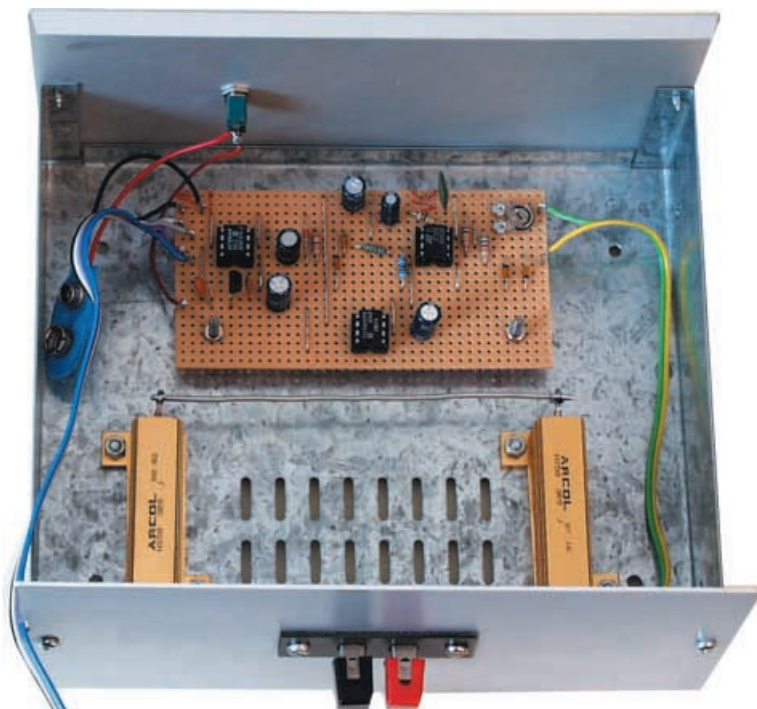
Multiplying the current and voltage readings provides the measured power level, and some further mathematics then limits readings to a manageable two decimal places. Some further mathematics then produce a value that can be used as the X2 co-ordinate of Line1, which is the pointer of the virtual panel meter.

### OBTAINING SOFTWARE

The PC Audio Power Meter's software is available from the EPE web site (free) or from the Editorial Office (a small charge applies). See this month's *Shoptalk* page. You need to have Visual Basic 6 already installed on your computer.

The program has been compiled to what is almost a stand-alone .EXE file (source code is also supplied). There are no INP and OUT commands in Visual Basic 6, and these are added using a Freeware file called **INPOUT32.DLL**. This file should be included in the same directory as the program file, or in the Windows/System directory.

No installation is required and the program can be run using the usual Start button followed by the Run option. Alternatively, find the program file using Windows Explorer and then double click on it. □



Completed unit showing the two heavy-duty, spring-loaded loudspeaker output terminals fixed to the rear panel.



# READOUT

E-mail: [editorial@epemag.wimborne.co.uk](mailto:editorial@epemag.wimborne.co.uk)

**John Becker addresses some of the general points readers have raised. Have you anything interesting to say? Drop us a line!**

## WIN A DIGITAL MULTIMETER

A 3 $\frac{1}{2}$  digit pocket-sized l.c.d. multimeter which measures a.c. and d.c. voltage, d.c. current and resistance. It can also test diodes and bipolar transistors.

Every month we will give a Digital Multimeter to the author of the best Readout letter.



## ★ LETTER OF THE MONTH ★

### MIRRORS AND SMOKE

Dear EPE,

I just would like to share my experiences that prove, beyond all doubt, that PICs work with mirrors and smoke.

Having built the wonderful *PIC Icebreaker* board (Mar '00) and got the old l.c.d. flashing, the time had come to move onto more adventurous projects. As I enjoy playing with PCs as well, the COMMS port seemed a good place to go to. After studying all the data books and writing a simple loop to send a set of letters out of the PIC's USART, I dumped the program into the 16F877. Feeling very bold, the baud rate was set to 19.2Kb, HyperTerminal was fired up, only to display a whole bunch of gobbledegook.

Then I remembered that your *8-Channel Data Logger* (Aug/Sep '99) also sends data to the PC. Checking its circuit I found that signal polarities were the same as mine! A lot of scratching on the Internet revealed that "on an RS232 port, a digital High is represented by a Low voltage", which is upside-down.

Then it also strikes me! The data book is printed in the Northern hemisphere and the *Data Logger* was also designed up North, and here I am sitting in the Southern hemisphere! So all I have to do now is turn the Data Book upside-down and everything should work fine. No go! Now the levels are right, but I am sending the Stop Bit first, then the MSB, followed by all the other bits and then the Start Bit!

But hang on, if I turn the book right way up again and put a mirror there . . . Aaaaah, now it looks better and I can push up the baud rate to 115Kb and it all hums along merrily with "The Quick Brown Fox . . .". So it seems that we "Southerners" definitely need a mirror to make the USART work properly!

Now comes the proof that they also need smoke to work. I accidentally let some smoke out of a PIC the other day using 20V and it stopped working. Unfortunately, it dispersed before I could catch it all so that I could not put it back to make the PIC work again. Anyone out there got a PIC re-smoker for me?

Seriously though, nowhere in documentation that I have seen does it state that an inversion is required to get from a PIC into RS232. With a simple transistor inverter she works like a dream.

Thanks a lot to *EPE* for giving me the tools to get started with PICs. The articles and circuits were very helpful.

**Mike Von Der Heyden,  
Kimberley, South Africa**

*Thought provoking comments Mike! The world of serial is full of wonders and little documentation. In my Data Logger I used interrupts in machine code with an inversion.*

*However, we thought that all constructors were familiar with the concept that some electronics components should only be used the "right way round" and so guess that digital Highs and Lows might be equally polarity (and thus hemispherically) conscious! (Only joking, I must reassure the novices amongst you – our projects are globally compatible without reorientation, with the possible exception of my Musical Sundial, Jun '99!)*

*And, er, yes, you've got to keep the smoke in any electronics component. Once it gets out, the component's demise is usually assured. Perhaps there might be a way, though, that I can incorporate a PIC re-smoker with the new PIC Toolkit for Windows that I'm working on! Any of you ingenious readers have suggestions on this point?*

### BLANKET WEED CONTROL

Dear EPE,

I've been looking to buy a commercially available electronic blanket weed controller for my pond, but am astounded at the prices being asked for what appear to be relatively simple devices. I know of several people also keen to get one, but not at the prices quoted. This would seem to be an ideal project for you to feature.

It would appear that these devices use a variable low frequency transmitter (1kHz to 7kHz) with two wires wrapped around the outflow pipes, each wire in opposing directions. The exact detail of how it all works is vague. It seems that calcium carbonate is an important part of cell wall chemistry in the weed. If the mineral is modified (polarised? ionically modified?) the weed can't absorb it so well and growth is retarded. Or so I've read.

The problem is, very mixed feedback on results. Many purchasers are impatient or have other water problems which hinder the function of the unit. Interest is huge – but who will risk spending lots of dosh if it might not work?!

For some idea on the level of interest, try a quick net search for "electronic blanket weed" via [www.google.com](http://www.google.com), it yields over 2000 sites!

**Brendan Cunningham, via the Net**

*It seems that the technique might be similar to water pipe descaling, a subject that we have covered constructionally in the Experimental Electronic Pipe Descaler (Aug '93) and PIC Pipe Descaler (Oct '97). Both units used variable frequency, the latter unit using a PIC to control it.*

*Following publication in '97, a great deal of Readout correspondence resulted, and which seemed to (by-and-large) confirm the effectiveness of the device. As to whether it might work as you require, I cannot speculate. Do any readers know?*

### VB AND PORTS

Dear EPE,

How do you access a PC's ports when using Visual Basic? What are the equivalents of the QBasic INP and OUT instructions? I've just started playing with VB5 (cheap because a generation behind!) and without the ability to access those ports the whole point of a computer disappears. Maybe the Pro version has them. Any ideas?

**Alan S. Raistrick, via the Net**

*Well, Alan, I'm using VB6 and accessing the parallel printer port using the Freeware INP/OUT32.DLL as introduced to us by Robert Penfold in his Interface series. It is available for free download from our web site (in the Interface folder) and is also on EPE Disk 3. It is extremely easy to use.*

*It seems crazy, though, that VB does not allow direct access to the ports. Such a facility is an imperative for the type of software that I write for a PC.*

*Incidentally, although Chat Zone readers have given me advice on using VB and the comms (serial) ports, I have not yet achieved fully satisfactory interfacing with them. Can any readers point me (and others) to a freeware/shareware serial interface program that is as easy to use as INP/OUT32?*

### VB FOR FREE!

Dear EPE,

I'm glad to see that you are supporting Visual Basic. I have a lot of experience with it and always look forward to your PIC/VB projects. May I recommend to the readers who may not be able to afford any of the VB suites, that there is a free version available for download at:

<http://support.microsoft.com/support/VBasic/VB5CCE/default.asp>.

This is the VB5 Control Creation Edition, and will be of use for most Visual Basic projects.

**Paul Finnerty, via the Net**

*Thanks Paul. I'm finding VB6 superb to work with. Wish I'd got to know how to use VB years ago – my Teach-In 2000 series would have benefited and allowed even more facilities, and fewer programming commands! Upgrading from VB5 to VB6 is not greatly expensive (neither is buying VB6 directly).*

*Coincidentally, another reader has recently sent the following as well:*

Readers may wish to try the Control Creation

Edition, available via <http://msdn.microsoft.com/vbasic/downloads/cce/>. This is intended to be used for creation of ActiveX controls but it can be used for standard EXE based applications with the limitation that the project cannot be compiled to an EXE file. It is functional in all other respects.

**Mark Jiggins,  
Hersham, Surrey,  
via the Net**

*Thanks Mark, it seems like readers are spoiled for VB choice!*

### PIC PORTS

Dear EPE,

Can PICs store data on their ports?

**Peter Mayhew, via the Net**

*Yes, Peter, as I discussed and showed in my PIC Tutorial of Mar-May '98. Any data written to a PIC's port will remain there until intentionally changed. It can also be manipulated while remaining on the port, rotated, ANDed, ORed, inverted, etc.*



## PROGRAMMING HISTORY

Dear EPE,

I was interested in Peter Kelly's *Letter of the Month* (Dec '00), and especially his frustration with the common programming construct **FOR A = I to K**. Most programmers actually use I, J, K, L, M for loop counters, and not because "I" might stand for Index. Their use (and I don't condone it) is largely historical.

Fortran IV (blimey that seems a long time ago) defined these variable names as *Integers*. So they were used as loop counters. It seems to have stuck, even if some programmers don't know why.

We have come a long way in language development, many of us will remember programming languages (particularly the many forms of BASIC) where the variable name was limited to two characters. Indeed in my early programming days using DEC's BASIC+ under RSTS/E this is what we were limited to. Somehow we managed to turn out really quite sophisticated applications. So there's a bit (ouch) of programming history for the archives. Thanks for a great magazine.

**Godric Goodrich (G4NLA),  
via the Net**

Ah, now "I" know – thanks Godric! When I was teaching myself how to program (late 1970's) I too was limited to two characters for variables. It's amazing how one coped. I was also limited to only 32K of memory in which to contain my programs, and to 1MHz at which to run them (Commodore PET). (It was also when I learnt to hate "I" as a variable name!)

What such limitations taught, though, was the ability to condense and refine one's code to the absolute minimum. These days there is so much memory and speed available that code compactness often "goes out the window (Windows?!)" – sadly, this can encourage programmers to become sloppy in their code writing, using far more program lines than are really needed, and which could be achieved with a bit more thought (although with more time spent at it, it has to be admitted).

I also recall using cassette recorders as the storage medium. These took ages to read and write. At times I could power up the PET and have time to make coffee before it had loaded a program! It was not until the early 80's that disk drives became available for the PET (storing about 360K of data per disk).

At the time of writing, Dell Computers have just advised me that they now have PCs with Pentium 4 processors running at 1.5GHz (1500MHz), and having disk drives storing 40 gigabytes, all for around £1600 (about half of what the PET system cost me in total 20-odd years ago!)

## WHAT PROGRAMMER?

Dear EPE,

I have just started thinking about programming my own PICs, having previously bought only programmed ones. After reading different advertising extracts, I am now totally confused about which to buy? Which is the best all rounder for the newcomer and which will program the widest range of chips?

**Mark Cowley, via the Net**

As you seem to have found, Mark, there are many commercial PIC programmers on the market. Indeed Microchip appear to encourage people to design their own programmer and provide rudimentary information about doing so in their data books etc.

We are not familiar with the programmers available from our advertisers and cannot comment on their merits. However, I can make two observations.

First, it seems likely that the programming facilities available from Microchip (e.g. MPLab, MPASim, MPASM) will cover the entire range of their PIC and other products. This would seem to be a route you should investigate as you want "the widest range". However, my own (brief)

experience with MPASM was that it seemed slow to access when developing program code.

Another choice open to you is my PIC Toolkit Mk2, originally published in May-Jun '98, with additional software enhancements since then, the latest (V2.4) having been published with the Dec '00 issue. As a frequent writer of programs for PICs, I placed a very heavy emphasis on the speed and ease of use of Toolkit.

I am currently working on Mk3 (Toolkit for Windows) which has even more facilities. Toolkit, though, is principally designed for use with the PIC16x84 and PIC16F87x EEPROM-based devices (although there are some other PICs that it can also program).

## TEACH-IN 2000 CD

Dear EPE,

I found out about your *Teach-In 2000* electronics series (Nov '99 – Oct '00) in recent magazines. This is just what I've been looking for as a practical introduction to electronics. I have little electronics experience and no equipment.

I was wondering if there is a resources pack available for this series, or do you recommend a particular component supplier? Are the articles available as a stand-alone package, or do I have to purchase the back issues of the magazine?

**Andrew Fielden, via the Net**

There are two choices now available, Andrew. Back-issues of the magazine in printed paper format can be bought as stated on the Back Issues pages in any edition of EPE. The software that accompanies that format is available on a 3.5-in disk, as stated on the PCB Service page or free from our ftp site.

Alternatively, you can now buy the recently introduced *Teach-In 2000 CD-ROM* which includes the full series in PDF format (which can be viewed under Acrobat), and also the software. The CD-ROM version also includes Alan Winstanley's Basic Soldering Guide as a bonus article!

At the time that the series commenced, the following companies advised us that they were supplying some or all of the components: ESR Electronic Components, Magenta Electronics, FML Electronics, N.R. Bardwell – see their adverts for contact details.

## MPSIM TUTORIAL

Dear EPE,

Over the past couple of years your *PIC Toolkit*, *PIC16F87x* and *PIC Tutorial* articles have been most informative and interesting and must have given many of your readers a much better understanding into the operation and uses for these devices.

I believe that, as a sequel to these articles, a brief tutorial on the Microchip simulator MPSIM would be of great help, not only to the more experienced programmer, but particularly to those just starting. This simulator software (freely available), not only allows the program to be executed one step at a time, but also allows the contents of any of the registers to be displayed in either binary, decimal or hexadecimal or all three, so that the effects of each step can be watched.

This feature is particularly useful when studying the Status register flags after an instruction. This software also has the advantage of not requiring any extra hardware.

**Walter Scanes,  
Stroud, via the Net**

Personally, I am quite content to develop code in "real-time" by running it directly on a PIC. There are many easy techniques available for being able to examine register values when you want, including temporary attachment of I.e.d.s, alphanumeric I.c.d.s or direct interface to a PC.

However, I recognise that MPSIM offers an important programming development facility, and one which I believe many readers find to be invaluable. We will give thought to your helpful suggestion Walter.

## WHY NOT USE C?

Dear EPE,

Regarding the *Readout* discussion on a replacement for QBasic, Visual Basic and Delphi are unique to PCs so I wondered if some of your readers (especially students) might consider learning C. This language is useful for programming microcontrollers and PCs. C is defined by an ANSI standard and hence it is possible to write portable code that will work on many machines with a few or no changes. It is a compiled language and is thus fast (Visual Basic is partially interpreted). A free DOS ANSI C Compiler is available from Borlands website, go to [www.borland.com](http://www.borland.com) and click Community, Login and Downloads.

Even if you don't use a compiler, C is a very useful basis for writing pseudocode for your assembly language programmes. This is because it was designed to be able to do almost anything assembly language could do. And, because its designers didn't like typing, C will save you writer's cramp!

Also, C is useful for employment as it is replacing assembly language for programming microcontrollers. C is a subset of the new language ANSI C++, while Borland C++ Builder is the C++ equivalent of Visual Basic.

I found the best C book to be *The C Programming Language* (second edition) by Brian W. Kernighan and Dennis M. Ritchie (known as K&R2) which describes the C89 ANSI standard. K&R2 is sort of the official book on C and has the advantage of being short.

**Alan Bradley, via the Net**

Thanks for your comments Alan. Knowing a bit about C, I appreciate your sentiments. However, we do not think that the majority of our readers have an interest in the language and so do not feel that we should "take it on-board". What do others think?

## HOT OFFER

Dear EPE,

I recently built the *Temperature Interface* of Oct '00. As I use Linux and not MS Windows I wrote a small C program to control it. This is a command line program with only a text output at present. If I get time to learn a bit more I will add a pretty GUI front end.

In the meantime, I thought I would let you know there is life outside MS Windows. If anyone wants a copy of my program they can E-mail me at [n.elliott@ntlworld.com](mailto:n.elliott@ntlworld.com)

**Norman Elliot, via the Net**

Thanks Norman. Now, Linux, there's a name we have not had mentioned in *Readout* so far as I recall (will we see it again, eh, readers?).

## ZAPPING PICS

Dear EPE,

Can static electrical damage to a PIC cause partial changes to its stored programme/performance, or would it always cause a total failure?

**Alex Cunningham, via the Net**

It seems highly likely that program code could be disrupted under some conditions of static electrical exposure. Whilst one might normally expect total fatality from static discharge, it is possible that the discharge intensity might decay as it travels through the structure of the PIC (or other semiconductor device). This would cause damage to some parts but not others.

Always discharge static electricity from yourself by touching a grounded (earthed) conductor before handling such devices, even though most modern devices are far more robust than they used to be some years ago. Also, always ensure that your soldering iron is earthed to prevent electrical charge building up on its body as well.

If the integrity of a PIC is suspect it is always worthwhile trying to reconfigure and reprogram it.



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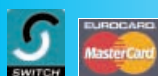
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**W**HEN something more robust, or more easily read, than a moving coil meter is needed, one of the LM3914-6 family of dot- or bargraph drivers and an l.e.d. display will usually provide a solution.

Manufactured by National Semiconductors, this “family” of chips (three) is extremely versatile. A single resistor and ten l.e.d.s are the only extra components required to produce a basic voltmeter or signal-strength meter. Two or three more resistors enable sensitivity to be adjusted, or the range expanded until a small, but critical, voltage change fills the entire display.

## INTERNAL STRUCTURE

The internal arrangement of the LM3914 i.c. is shown in Fig.1.

## The Comparators

At the heart of the device is a chain of ten resistors which set the bias on ten comparators so that l.e.d.s are switched on sequentially as the input voltage rises. The LM3914, 5 and 6 are identical apart from the values of the resistors in the voltage divider chain.

In the LM3914 the resistors have equal values to produce the *linear* response required for voltmeter applications. The resistors in the LM3915 are scaled *logarithmically*, and span 0dB to 30dB in ten 3dB steps, making this version suitable for signal-strength and power meters. The resistors in the LM3916 are related in a *semi-log* fashion to simulate a VU meter.

## Input Buffer

A high input impedance buffer stage minimises loading on the circuit under

measurement. The stage is protected against reverse polarity inputs by a shunt connected diode, and up to 35V can be applied to input pin 5 before any damage occurs.

This can be increased to 100V by placing a 39 kilohms resistor in series with the input. Pin 5 *must* be connected to the 0V rail via a resistor of not more than 100 kilohms ohms or l.e.d. 10 will lock on.

## Reference Voltage

Although the ends of the resistor chain can be connected to external reference voltages, it is generally more convenient to use the reference produced within the i.c. Typically 1.25V (it can vary from 1.2V to 1.34V), it is brought out at pins 7 and 8.

The voltage at pin 7 (Reference Out) can be increased to a maximum of 12V by connecting pin 8 (Ref. Adj.) to the 0V rail via

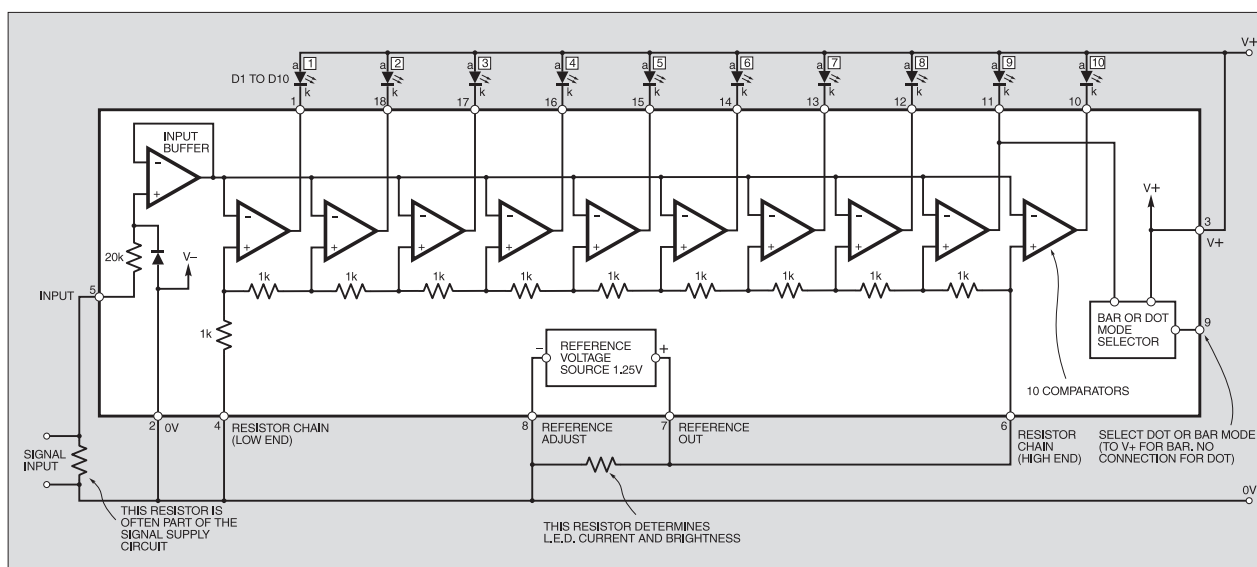


Fig.1. Block schematic diagram for the LM3914 l.e.d. bargraph driver showing the simplest external circuit. The LM3915 and LM3916 are identical except for the values of the internal resistors which determine the switching of the comparators.



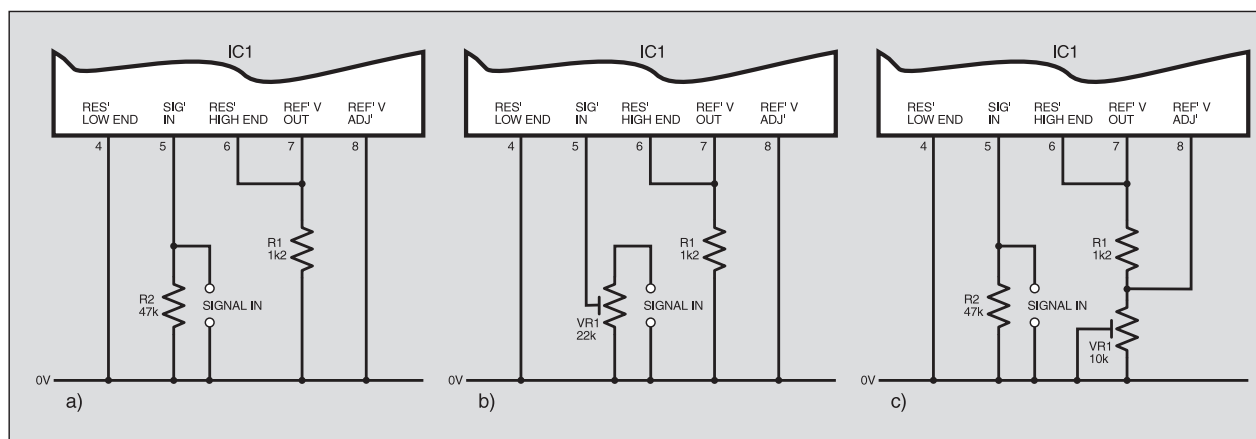


Fig.2a. Basic Sensitivity. Connecting the internal resistor chain directly across the 1.25V reference gives an input sensitivity, to i.e.d. D10 on, of 1.25V. Fig.2b. Reducing Sensitivity (Method One). Connecting the input to pin 5 via a preset potentiometer is the simplest way of reducing sensitivity. Fig.2c. Reducing Sensitivity (Method Two). Grounding pin 8 (Reference Adjust) via potentiometer VR1 increases the voltage across the internal resistor chain. This increases the input voltage required to turn i.e.d. D10 on. With a value of 10k for VR1, the sensitivity can be varied from 1.25V to more than 10V.

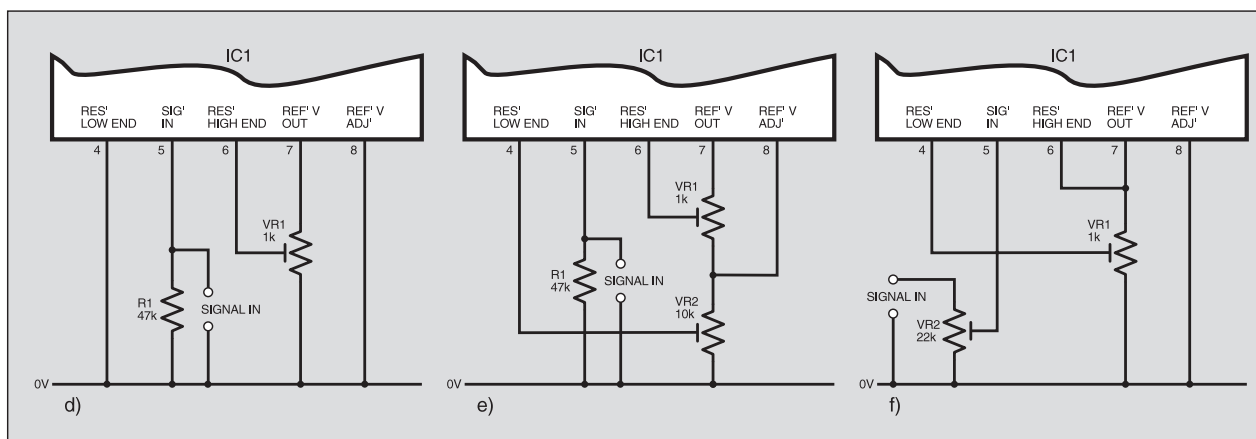


Fig.2d. Increasing Sensitivity. By connecting the "high" end of the internal resistor chain to the slider of potentiometer VR1, the input voltage to turn i.e.d. D10 on can be reduced to 0.1V or less. Fig.2e. Expanded Range (Method One). Connecting the ends of the internal resistor chain to the sliders of potentiometers VR1 and VR2 enables i.e.d. D1 and i.e.d. D10 "on" voltages to be adjusted. In this way a small, but critical, voltage change can be expanded to fill the entire display. Fig.2f. Expanded Range (Method Two). Connecting the "low" end of the internal resistor chain to the slider of VR1 enables range minimum (the input voltage required to turn i.e.d. D1 on) to be set between one tenth of range maximum and close to range maximum. Range maximum (the input voltage required to turn i.e.d. D10 on) is set by potentiometer VR2.

a resistor. The ability to increase the internal reference in this way makes it easier to set sensitivity over wider limits.

#### Bar or Dot Mode

A Bar or Dot mode selector is brought out to pin 9. Leaving pin 9 unconnected results in a dot display. Connecting pin 9 to pin 3 produces a bargraph.

#### Supply Voltage and Current

The supply voltage to the chip can be as low as 3V. It must, however, always be at least 1.5V more than the reference voltage applied to the "high" end of the internal resistor chain. The absolute maximum supply voltage is 25V.

Standby current (all i.e.d.s off) varies from around 3mA with a 5V supply to 10mA with a 20V power supply rail.

#### FIXING I.E.D. CURRENT

Current flow through *each individual i.e.d.* is ten times the current drain on the internal reference. I.E.D. current can, therefore, be programmed by a resistor connected between pin 7 and pin 8 (see Fig.1).

If the internal resistor chain is connected across the reference source (it usually is) the current through it must be added to the current through the programming resistor. When the LM3914 is used, the total resistance of the chain is nominally 10 kilohms, and i.e.d. current can be calculated from the following formula:

$$\text{I.E.D. current} = 10 \left( \frac{1.25}{R} + \frac{1.25}{10k} \right)$$

when  $R$  is the value of the programming resistor.

With a 1.2k programming resistor, individual i.e.d. current is:

$$10 \left( \frac{1.25}{1200} + \frac{1.25}{10000} \right) = 11.6\text{mA}$$

and the current in bargraph mode with all i.e.d.s on would, of course, rise to 116mA.

The reference voltage and value of the resistor chain can vary significantly between samples of the i.c., and some departure from the calculated current can be expected. The resistor chains in the LM3915 and LM3916 exceed 20 kilohms, and their contribution to i.e.d. current can usually be ignored.

## SENSITIVITY AND RANGE

The input voltage required to turn i.e.d. 10 (D10) on is equal to the reference voltage applied to the "high" end of the resistor chain. Similarly, the input required to turn i.e.d. one (D1) on is determined by the voltage applied to the "low" end.

There are limitations. The "low" end of the chain cannot be taken below the 0V rail, and the potential on the "high" end cannot exceed 1.5V below the power supply voltage. The internal reference can be set no higher than 12V.

The various ways in which the sensitivity and measurement range can be adjusted are illustrated in Fig.2a to Fig.2f. A brief description of the various methods of adjusting the input sensitivity follows:

#### Basic Sensitivity (Fig.2a)

Connecting pin 6 to pin 7 applies the internal reference to the "high" end of the resistor chain and the input voltage required to turn i.e.d. 10 (D10) on is, therefore, fixed at 1.25V.

The "low" end of the chain, pin 4, is connected to the negative terminal of the

reference, pin 8, via the 0V rail. The input voltage required to turn l.e.d. one (D1) on is, therefore, one-tenth of 1.25V or 125mV, and each increment of 125mV turns another l.e.d. on.

L.E.D. current is programmed by resistor R1 which is, in effect, connected across the internal reference source.

#### Reducing Sensitivity (Fig.2b):

##### Method One

Applying the input signal via potentiometer, VR1, enables the voltage for l.e.d. 10 on to be set at any level above the 1.25V internal reference. Inputs much in excess of 50V should be connected via a fixed resistor of suitable value to avoid the power rating of the potentiometer being exceeded.

#### Reducing Sensitivity (Fig.2c):

##### Method Two

The reference voltage at pin 7 can be increased by connecting pin 8 to the 0V rail via a resistor. In Fig.2c, the current flowing in resistor R1 is grounded via preset potentiometer VR1 (wired as a variable resistor), thereby increasing the voltage at pin 7 and pin 8. Applying this increased reference voltage to the "high" end of the internal resistor chain increases the voltage required to turn l.e.d. 10 on.

The formula relating resistor values to reference voltage is:

$$\text{Reference voltage} = 1.25 \left( 1 + \frac{VR1}{R1} \right) + VR1 \times \frac{80}{10^6}$$

(The above formula allows for an 80µA current flowing out of pin 8 to ground via VR1.)

By making the resistor between pin 8 and ground (0V) a 10 kilohms preset potentiometer, the reference voltage can be varied from 1.25V (VR1 at zero resistance) to 12V (VR1 near maximum).

#### Increasing Sensitivity (Fig.2d)

The basic sensitivity of 1.25V can be low for some applications. If preset VR1 is connected across the reference voltage and its slider (moving contact) taken to the "high" end (pin 6) of the internal resistor chain, the input to turn l.e.d. 10 on can be varied from 1.25V down to 100mV.

#### Expanding the Range (Fig.2e):

##### Method One

Sometimes it is desirable to expand a small, but critical, voltage range to fill the entire display. Battery condition checkers often rely on circuits of this kind.

Range maximum is set just above the fully charged or "fresh" voltage, and range minimum is set a little below the voltage at which the working of the equipment would be impaired. Different coloured l.e.d.s representing "good", "acceptable" and "dubious" ensure an easily read display, and a resistor to simulate the normal load should be wired across the cell under test.

In Fig.2e, preset potentiometer VR2 increases the reference voltage at pin 7. The "low" end of the internal resistor chain (pin 4) is connected to its slider enabling range minimum to be shifted over wide limits.

Adjustment of range maximum is facilitated by connecting the "high" end of the chain (pin 6) to the slider of VR1.



*Voltmeter with adjustable input sensitivity (1.25V to 10V) circuit board. See Fig.2c for circuit and Fig.10a for p.c.b. details.*



*Signal-Strength Meter (dot-mode) with amplified and rectified input. See Fig.2a for sensitivity fixing, Fig.5 for input circuit and Fig.10e for p.c.b. details.*

The resistance of VR2 should be chosen to increase the voltage on pin 7 to a level just above range maximum. If necessary, connect fixed and variable resistors in series to produce the desired value.

#### Expanding the Range (Fig.2f):

##### Method Two

A more versatile method of expanding the range is shown in Fig.2f, where the circuit is configured for a basic sensitivity of 1.25V. Connecting the slider of preset VR1 to the "low" end of the resistor chain enables range minimum to be set anywhere between one-tenth of range maximum and close to range maximum.

Range maximum is set at any level above 1.25V by potentiometer VR2.

### ACCURACY

Accuracy is partially dependant on the switching precision of the comparators, and their performance improves as the voltage across the internal chain of resistors approaches its maximum value. For this reason, the sensitivity adjusting circuits given in Fig.2c and 2e are to be preferred when accuracy is paramount. The circuits in 2b and 2f will, however, function with power supply voltages down to 3V.

Temperature variations, over a 0°C to 70°C range, have a negligible effect, especially if the voltage across the internal resistor chain is kept high.

When considering the question of accuracy, it should always be remembered that this method of displaying voltage lacks the precision of a digital or large moving-coil meter. The l.e.d.s are switched in a series of one-tenth steps and, to avoid display ambiguity, one l.e.d. fades out whilst the next is switching on.

Unless, therefore, there is considerable expansion, the display inevitably represents an approximation of the voltage being measured.

### DISSIPATION

The manufacturers of the devices quote an absolute maximum power dissipation of



*Bargraph display with "warning" flasher. Sensitivity adjustable from 1.25V upwards. See Fig.4 for circuit and Fig.10c for board details.*



*Remote Relay Driver circuit board. See Fig.7 for circuit diagram and Fig.10f for board details. It is possible to control up to 10 relays, using the control board of Fig.9.*

1365mW, and this figure has to be de-rated if the ambient temperature is higher than normal. When the display is configured in the bar mode, it is prudent, therefore, to check that total dissipation does not exceed, say, 600mW when *all* l.e.d.s are on.

Voltage drop across the l.e.d.s is determined by colour. It is near enough 2V for red, yellow and green l.e.d.s, and around 3.6V for white and blue.

To calculate dissipation, deduct the l.e.d. voltage drop from the supply voltage to give the voltage across the i.c., and multiply this by the total l.e.d. current plus, say, 10mA for device standing current.

With red l.e.d.s working at 10mA, and with a supply voltage of 12V:

Voltage across i.c. = 12 - 2 = 10V.

Maximum current = 10 + (10 × 10) = 110mA

Maximum dissipation = 10 × 110 = 1100mW, which is too high for safety.

Adopting dot instead of bar mode will bring dissipation within safe limits, and l.e.d. current can be reduced by increasing the value of the resistor between pin 7 and pin 8. However, for many applications using standard l.e.d.s, a current of 10mA is required to produce a bright enough display.

Dissipation can, of course, be reduced by reducing the supply voltage to the i.c., but it must always be 1.5V or more above the voltage applied to the internal resistor chain. When the supply to the i.c. has to be high for this reason, dissipation can be reduced by using a separate power supply of 3V or 5V for the l.e.d.s.

If separate supplies are inconvenient, dissipation can be kept within safe limits by placing a 470 ohm resistor in series with *each* l.e.d.. The manufacturers suggest a single resistor placed in series with the l.e.d.'s common anode lead (the l.e.d. end of this resistor should be bypassed to the 0V rail by a 10µF electrolytic capacitor). With this method there may be a perceptible reduction in brightness as the bargraph extends.

## STABILITY

The circuit may become unstable if the l.e.d. connecting leads are longer than 150mm. A 10 $\mu$ F electrolytic capacitor connected across the power supply rails, and mounted reasonably close to pins 2 and 3, avoids this possibility.

Instability can also arise if the internal resistor chain is connected to independent reference voltages of high impedance. Bypassing pin 6 to ground via a 100nF capacitor will eliminate any problems.

## L.E.D.S

The efficiency of l.e.d.s (light emitting diodes) in terms of light output for a given current varies considerably. The so-called "high brightness" l.e.d.s certainly produce a vivid display, but this is usually achieved by adopting current levels of 20mA or more.

If current economy is important, either to contain dissipation or to extend battery life, low current l.e.d.s, which are very luminous at 2mA, represent an ideal solution. The 3mm types seem brighter than their 5mm counterparts, no doubt because the light source is not obscured by so much plastic.

By using low current l.e.d.s in the dot mode with a 3V supply, and increasing the l.e.d. current programming resistor to 10 kilohms (R1 in Fig.2a), a very economical voltage display can be produced.

## BARGRAPH DISPLAYS

Rectangular l.e.d.s are more appropriate for bar graphs, and separate diodes can be combined into a ten l.e.d. display. A method of doing this is illustrated in Fig.3.

The provision of a bezel avoids the difficulty of cutting a neat rectangular slot in the instrument case, and l.e.d.s of different colour can be combined. The meeting faces of the l.e.d.s must be coated with dark paint before being glued together, or light spread will be a problem.

Ten segment displays can be purchased for little more than the cost of separate l.e.d.s. This does, however, deny the constructor the opportunity to mix l.e.d.s of different colours.

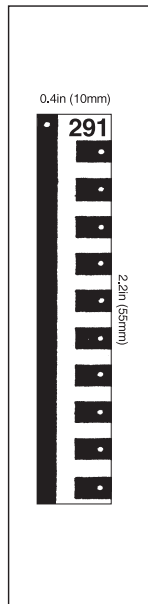
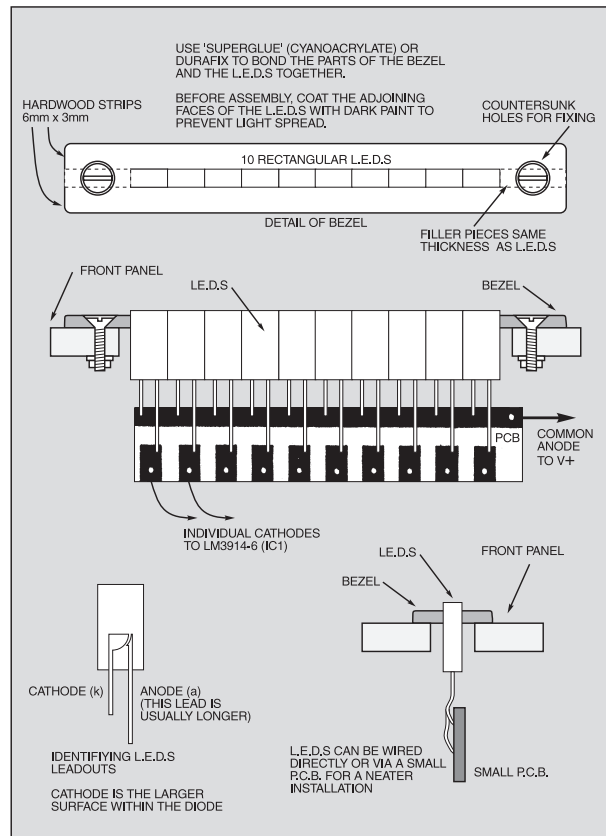


Fig.3b. Full-size L.E.D. Display foil master.

Fig.3a. Assembly details for making the l.e.d. bargraph.



"Homebrewed" bargraph display using separate l.e.d.s.

## FLASHING DISPLAYS

How the entire display can be made to flash when a critical voltage level has been reached is shown in Fig.4. Bargraph mode (pin 9 to pin 3) must be adopted with this arrangement.

The display can be made to start flashing from l.e.d. 2 onwards. Simply connect resistor R2 in series with the anode (a), and take the junction of resistor R3 and capacitor C2 to the cathode (k), of the l.e.d. where flashing is to start.

## SIGNAL STRENGTH METERS

Bargraph drivers are commonly used for signal strength and power meters. The LM3915, with its logarithmic response, is the natural choice for applications of this kind.

The simplest system involves the direct connection of the signal to pin 5. Remember to include a blocking capacitor if d.c. is present: a 220nF ceramic or polystyrene component is suitable.

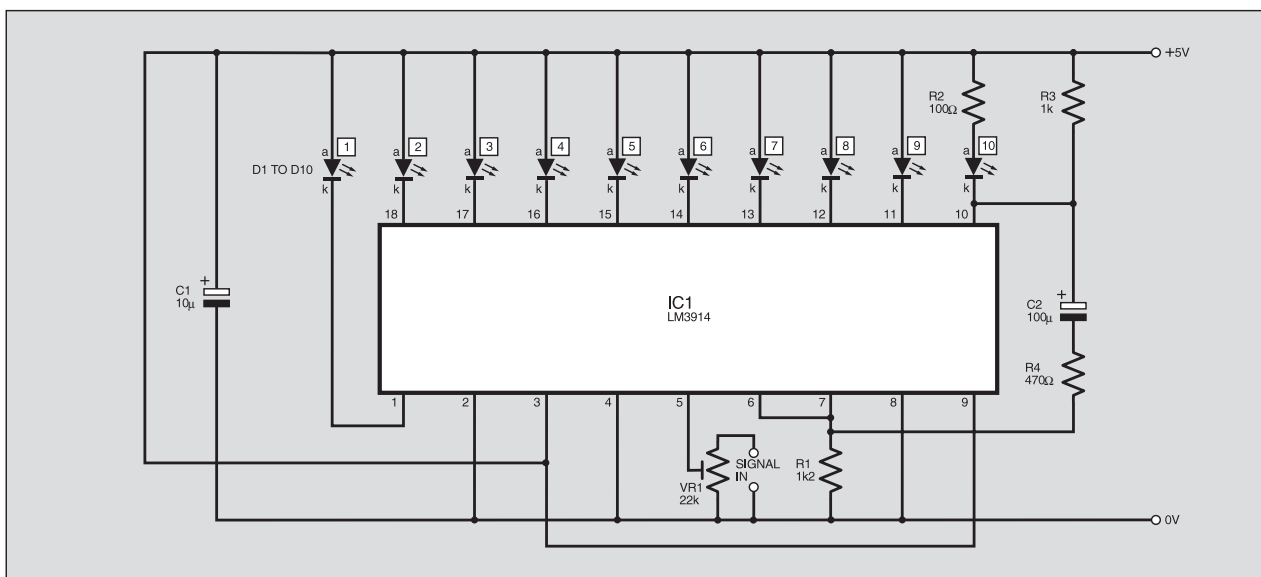


Fig.4. Circuit diagram for the Bargraph display, with alarm flasher. When D10 is activated it begins to flash.



The manufacturers recommend dot mode and a 30mA l.e.d. current when this method is adopted. If, however, the display seems patchy at high signal levels, try the bar mode and a lower l.e.d. current.

When a sensitivity greater than the basic 1.25V is required, use the circuit given in Fig.2d.

## RECTIFIERS

Better results can be obtained by rectifying the signal and applying d.c. to the bargraph driver. A suitable circuit is given in Fig.5.

Transistor TR1 amplifies the signal to ensure that diodes D1 and D2 are working in their conductive region. The diodes are arranged in a voltage doubling circuit, and preset potentiometer VR1 should be set just short of signal clipping in TR1 to ensure that they are driven hard. Potentiometer VR2 is then set to deliver the required input to the i.c.

The high input impedance of the field-effect transistor, TR1, minimises loading on the signal circuit, and reservoir capacitor C5 sharpens the l.e.d. display. The amplifier and rectifier circuit can be teamed with the basic i.c. arrangement illustrated in Fig.2a, and a 12V power supply is required.

If the bargraph mode is chosen, take one or other of the measures outlined earlier to

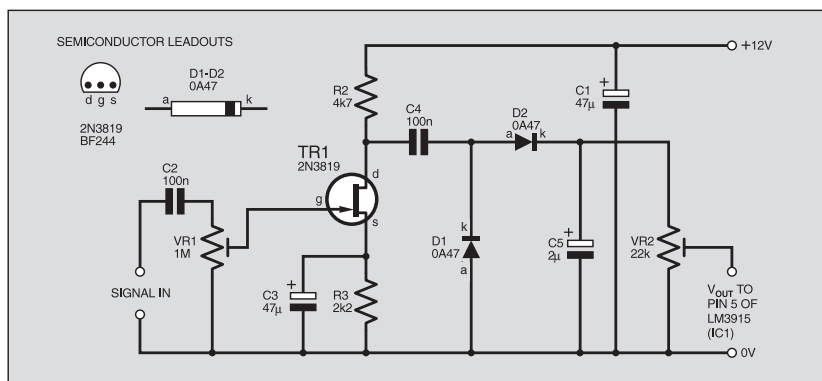


Fig.5. Amplifier and rectifier stages for the Signal Strength Meter. R1 is the l.e.d. brightness resistor, not shown here – see Fig.2a. VR2 acts as the input (pin 5) grounding resistor (R2 in Fig.2a).

therefore, display r.m.s. power levels. If peak power is to be displayed, set VR1 so that l.e.d. 10 (D10) lights when the voltage reading on the test meter is 0.707 times the value indicated by the formula in Fig.6.

## REMOTE RELAY DRIVER

If switching transistors and relays are substituted for the l.e.d.s, the LM3914 can be used to control up to ten functions via a two-wire link.

The circuit diagram for a Relay Driver set-up using the LM3914 is given in Fig.7. When one of the comparators draws current, the voltage developed across base/emitter resistor, R4 to R8, makes the relevant transistor collector (c) conduct and the associated relay coil is energised. Diodes D1 to D5 shunt the high voltage developed across the relay coil when the transistor turns off.

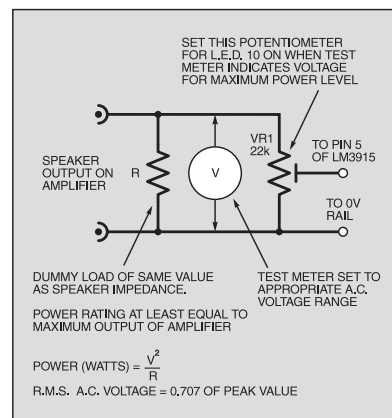


Fig.6. Setting up bargraph drivers to display peak r.m.s. power.

The combination of resistors R1 and R2 fixes the voltage across the resistor chain at 9V. This ensures a good difference between trigger levels and adjustment of the control voltages is less critical. Only

ensure that dissipation is not excessive. The stabilising capacitor across the power supply, C1, should be increased to 47μF when this circuit is used.

## POWER METERS

Signal strength meters can be adjusted to indicate power levels. The load is known (the speaker impedance quoted by the manufacturers), and the power delivered is, of course, proportional to the voltage developed across it.

How a dummy load, test meter and the bargraph driver are connected during the setting up process is shown in the circuit of Fig.6. Simply inject a signal into the amplifier, increasing it until the test meter indicates that the maximum power level has been reached, then set preset VR1 to light l.e.d. 10.

The formula relating power to voltage and load impedance is also given in Fig.6: e.g., with a 4 ohm speaker, 10 watts is being supplied when 6.3V is developed across the dummy load, 50 watts when the voltage is 14V, and 100 watts when the voltage is 20V.

The setting up signal should be below 1kHz because the accuracy of most test meters reduces at frequencies much higher than this. Provided the response of the amplifier is wide enough, 50Hz from a low voltage transformer can be applied if a signal generator is not available.

Test meters indicate the r.m.s. values of a.c. voltages, and the power meter will,

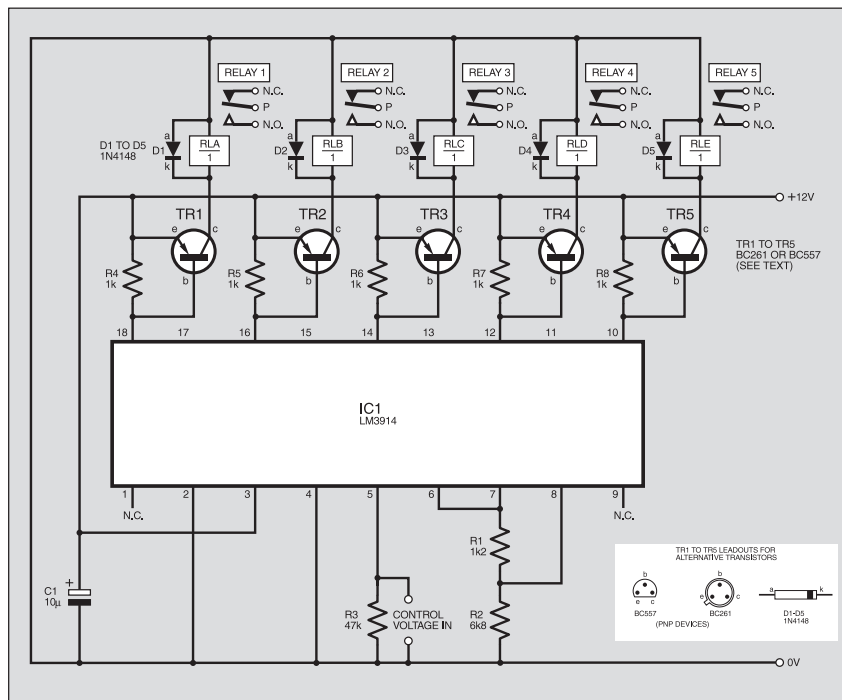


Fig.7. Circuit diagram for using the LM3914 as a relay driver. Remote control of up to ten relays, via two wires, is possible.

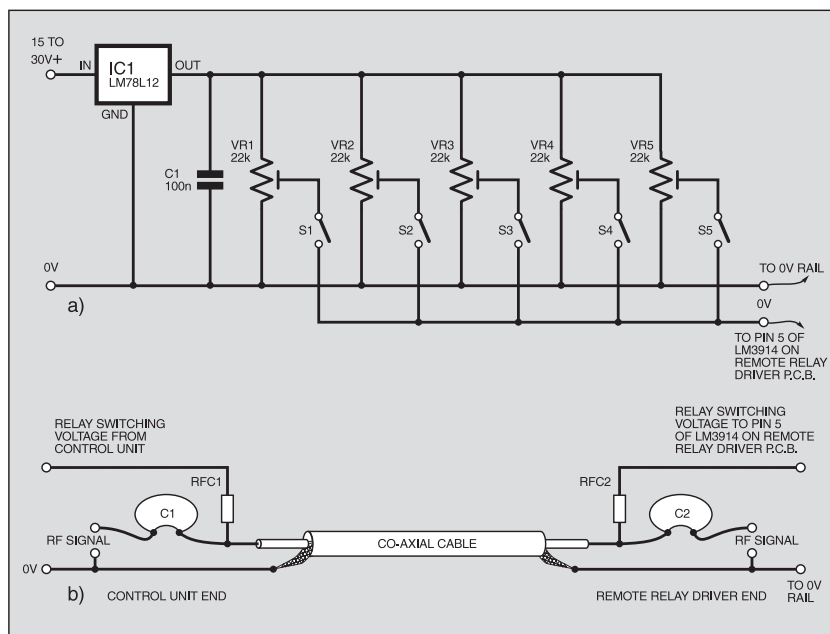


Fig.8. Control Unit and applying switching voltages via an r.f. signal cable. (a) circuit diagram and (b) cable interlink details.



Relay Control board (for 5 relays).

five relay circuits are shown, but all ten outputs from the i.c. can be used if desired.

A relay control board circuit diagram is given in Fig.8a. Control voltages are set by potentiometers VR1 to VR5 and selected by switches S1 to S5. Voltage regulator IC1 ensures that the correct voltage levels are maintained. Broad band r.f. noise developed by the i.c. is bypassed by capacitor C1.

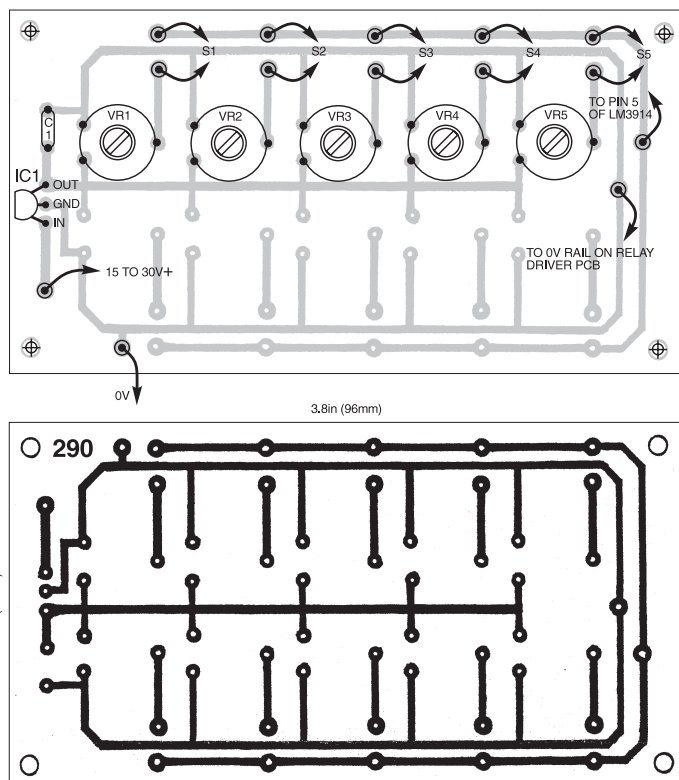


Fig.9. Relay Control p.c.b. component layout and foil master.

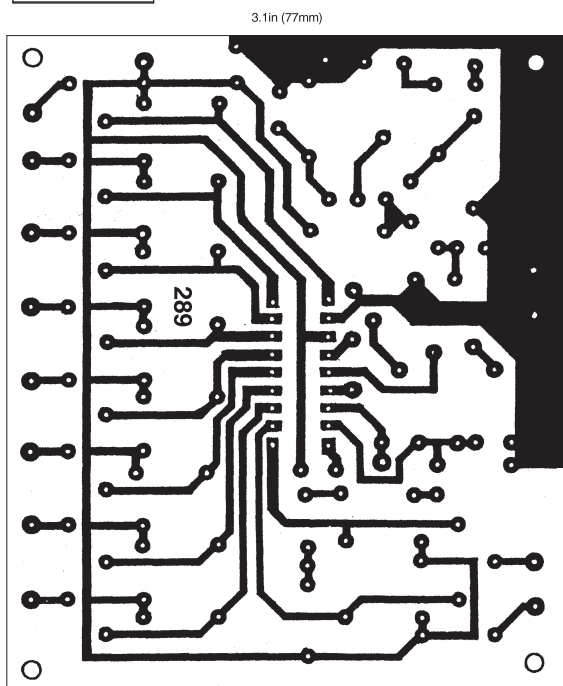
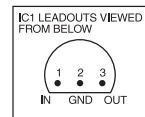


Fig.11. Full-size Multi-purpose L.E.D. Driver foil master.

This avoids problems when the control voltages are carried by an r.f. signal cable in the manner illustrated in Fig.8b. Here, r.f. chokes, RFC1 and RFC2, isolate the signals from the control circuitry, and blocking capacitors C1 and C2 prevent the flow of d.c. into the signal circuits.

Select the inductance of the chokes to suit the signal frequencies: e.g., 4.7mH for low and medium frequencies, and 1mH for medium and high frequencies. The capacitors can be 100nF ceramic type.

Alternatively, three-core cable can be used: one wire supplying low voltage power for the LM3914 and, say, drive motors, another the control voltages, and the third a common 0V rail.

The only disadvantage to the system is that only one relay can be activated at any one time. However, with up to ten circuits available, this is no great drawback.

## CIRCUIT ASSEMBLY

The full-size foil and component sides of a p.c.b. for the Relay Driver Control Board are shown in Fig.9. Although five circuits are shown, provision is made on both p.c.b.s for all ten to be installed should this be required.

The components for the various circuits are best assembled on a small printed circuit board (p.c.b.). The full-size, copper foil side of a multi-purpose board, which can accommodate all of the circuits discussed, is shown in Fig.11. The various topside component layouts are illustrated in Fig.10a to Fig.10f, also see the photographs. The board (one only) is part of a set which is available from the EPE PCB Service, codes 289/290/291.

It is a good idea to use a holder for the LM3914/6, and solder pins, inserted at the lead out points, ease the task of off-board wiring. Use a small crocodile clip as a heat-shunt when soldering the f.e.t. (TR1) and germanium diodes (D1, D2) for the "rectified" version of the Signal Strength Meter in Fig.5. Remember to include the wire links, and always check the orientation of electrolytics and semiconductors before applying power to the board.

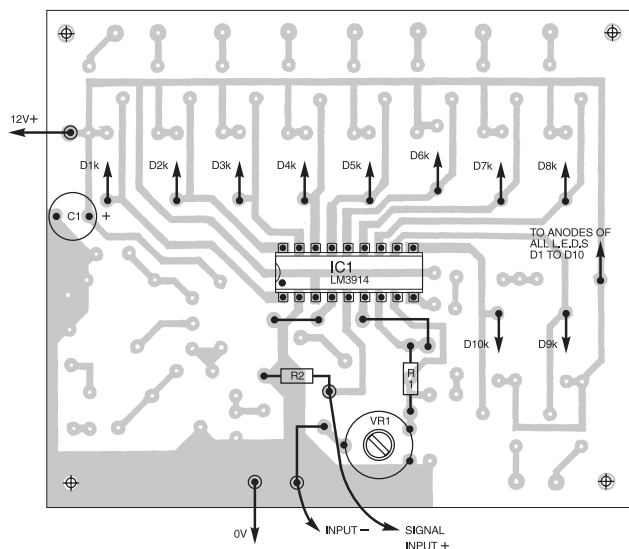


Fig.10a. Component layout for Voltmeter with adjustable input sensitivity (1-25V-10V). See Fig.2c for input circuit. C1 is a 10μF capacitor connected across the supply rails.

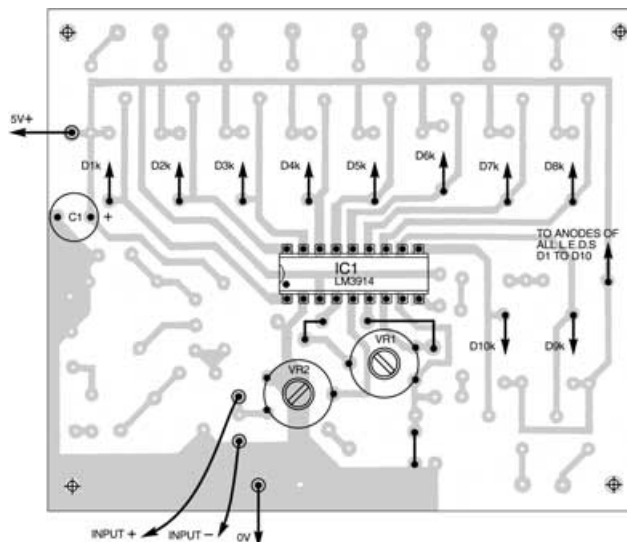


Fig.10b. Component layout for expanded range dot mode voltmeter. See Fig.2f for circuit.

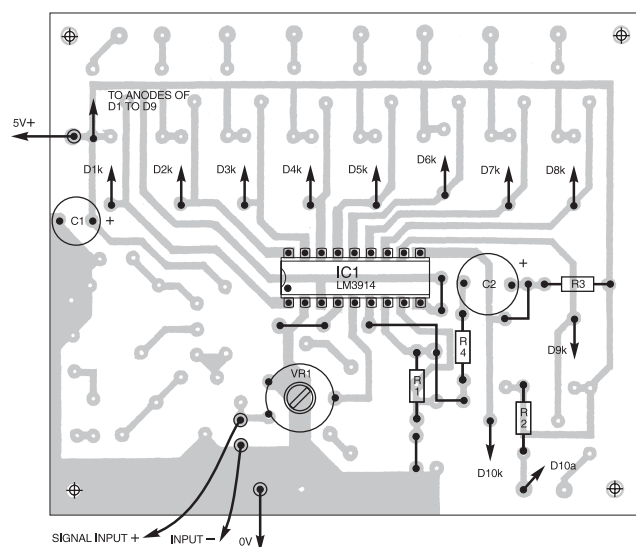


Fig.10c. Component layout for Bargraph display, with alarm flasher. Sensitivity adjustable from 1-25V upwards. See Fig.4 for circuit.

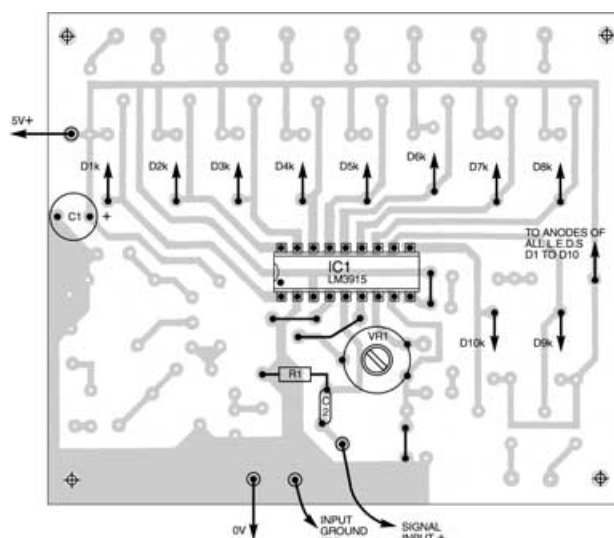


Fig.10d. Component layout for basic bar-mode Signal-Strength Meter. Input sensitivity adjustable over a 100mV to 1-25V range. See Fig.2d for circuit. C2 is a 220nF d.c. blocking capacitor at the input.

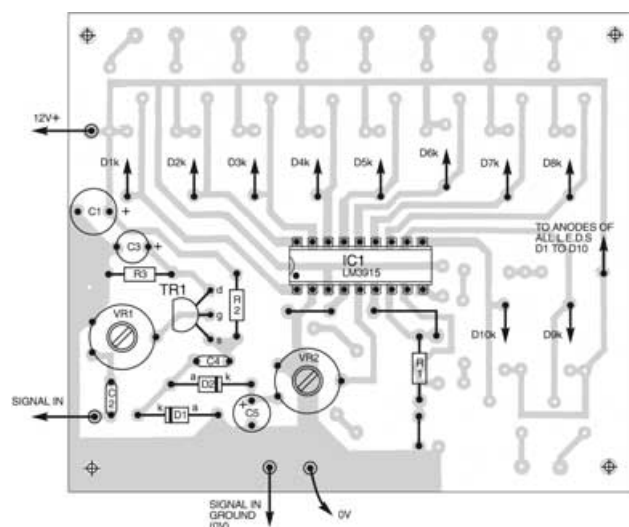


Fig.10e. Component layout for Signal-Strength Meter (dot-mode), with amplified and rectified input. See Fig.5 for input circuit. See Fig.2a for i.c. sensitivity fixing circuit.

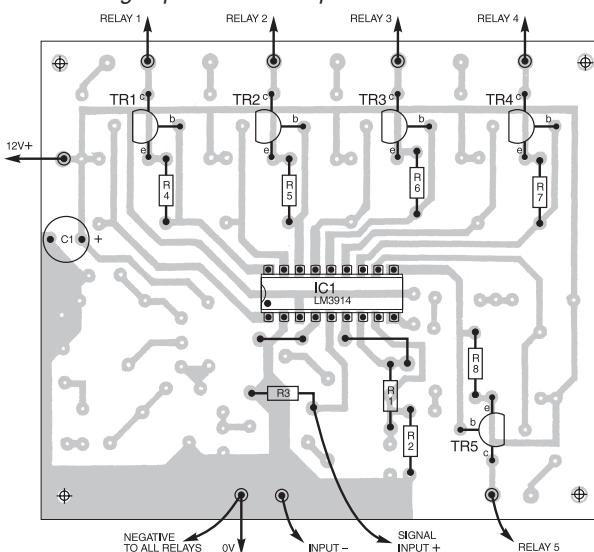


Fig.10f. Component layout for Remote Relay Driver. See Fig.7 for circuit diagram. Up to ten relays can be controlled.



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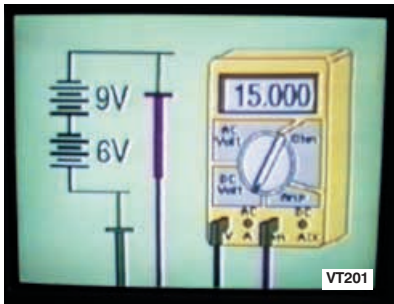
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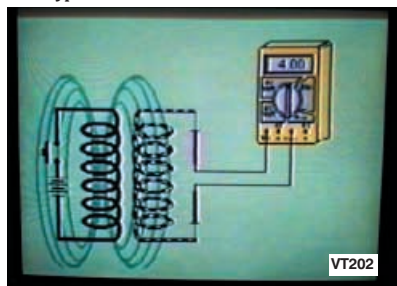
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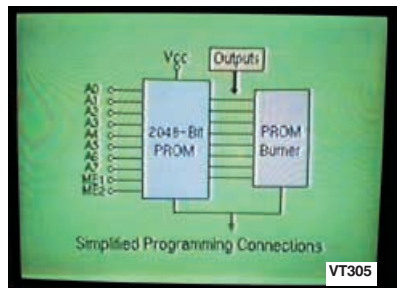
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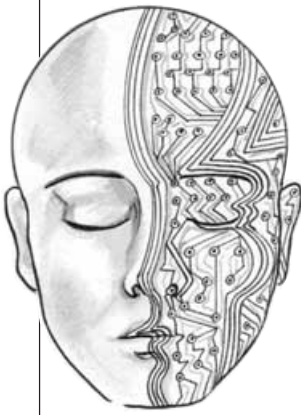
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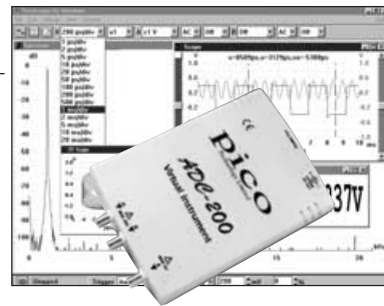
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Our regular round-up of readers' own circuits. We pay between £10 and £50 for all material published, depending on length and technical merit. We're looking for novel applications and circuit designs, not simply mechanical, electrical or software ideas. Ideas *must be the reader's own work and must not have been submitted for publication elsewhere*. The circuits shown have NOT been proven by us. *Ingenuity Unlimited* is open to ALL abilities, but items for consideration in this column should be typed or word-processed, with a brief circuit description (between 100 and 500 words maximum) and full circuit diagram showing all relevant component values. **Please draw all circuit schematics as clearly as possible.** Send your circuit ideas to: Alan Winstanley, *Ingenuity Unlimited*, Wimborne Publishing Ltd., Allen House, East Borough, Wimborne, Dorset BH21 1PF. (We **do not** accept submissions for *IU* via E-mail.) Your ideas could earn you some cash and a prize!



## WIN A PICO PC BASED OSCILLOSCOPE

- 50MSPS Dual Channel Storage Oscilloscope
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- Multimeter • Frequency Meter
- Signal Generator

If you have a novel circuit idea which would be of use to other readers then a Pico Technology PC based oscilloscope could be yours. Every six months, Pico Technology will be awarding an ADC200-50 digital storage oscilloscope for the best *IU* submission. In addition, two single channel ADC-40s will be presented to the runners-up.

## Garden Lighting Controller – Delayed Action

THE circuit diagram shown in Fig.1 provides on/off pushbutton control for a Garden Lighting System. In addition, there is a 1½ hour timeout facility, as well as remote control inputs at CMOS levels for external control use if desired.

In these days of "PICS with everything" this is an example of good old-fashioned logic. Assuming the lighting is off (IC2a at reset), IC3 is held at reset via OR gate IC1d.

Pressing switch S2 sets IC2a via OR gate IC1c, taking pin 13 high. This energises the relay RLA which switches on the lighting, via the relay contacts. Since pin 12 of IC2a is now low, IC3 is allowed to count.

Once the Q14 output, pin 3 of IC3, goes high, flip-flop IC2a is reset via IC1a and IC1b, removing the drive to transistor TR1. Further presses of switch S2 during the timing interval will reset the timer via IC1c and IC1d, so causing the time interval to start again. Pressing switch S1 at any time resets

the flip-flop and the timer via IC1b, IC2, and IC1d.

The 14-stage ripple counter IC3 contains a multivibrator clock, the frequency of which is set by C1, R6, and R7 to around 1.5Hz. After 8,192 cycles Q14 output will go high (and low again after a further 8,192 cycles, making  $2^{14}$  in all – ARW), which equates to a delay of 1.52 hours.

The contact arrangement of RLA1 is not shown as it depends on your application. The author used a d.p.d.t. relay, with its normally open contacts in parallel, switching the mains side of the lighting transformer. Ensure adequate fusing is provided and that you take care to **ensure full isolation** between the low voltage and mains parts of the circuit, if applicable.

### Remote Control

The remote control inputs provided were intended for a system based on the Holtek

HT12 series of encoders/decoders. Overall the system will then provide multipoint control, with the knowledge that if the lights are left on, they will turn off automatically, preserving the life of the lamps in the outside fittings. Note that the HT12D decoder chips have latching outputs and that if used in conjunction with this circuit, steps must be taken to ensure a momentary pulse is supplied.

As a final tip, I originally had a Hozelock 24V a.c. lighting set. Most systems are now 12V, so in order to use the original transformer I placed a 1N4001 diode in series with 12V 4W lamps. By arranging an equal number of fittings to operate on each half cycle (reversing the orientation of the diode), the transformer sees a balanced load and the 12V lamps will not burn out.

David Geary,  
Blackheath,  
London.

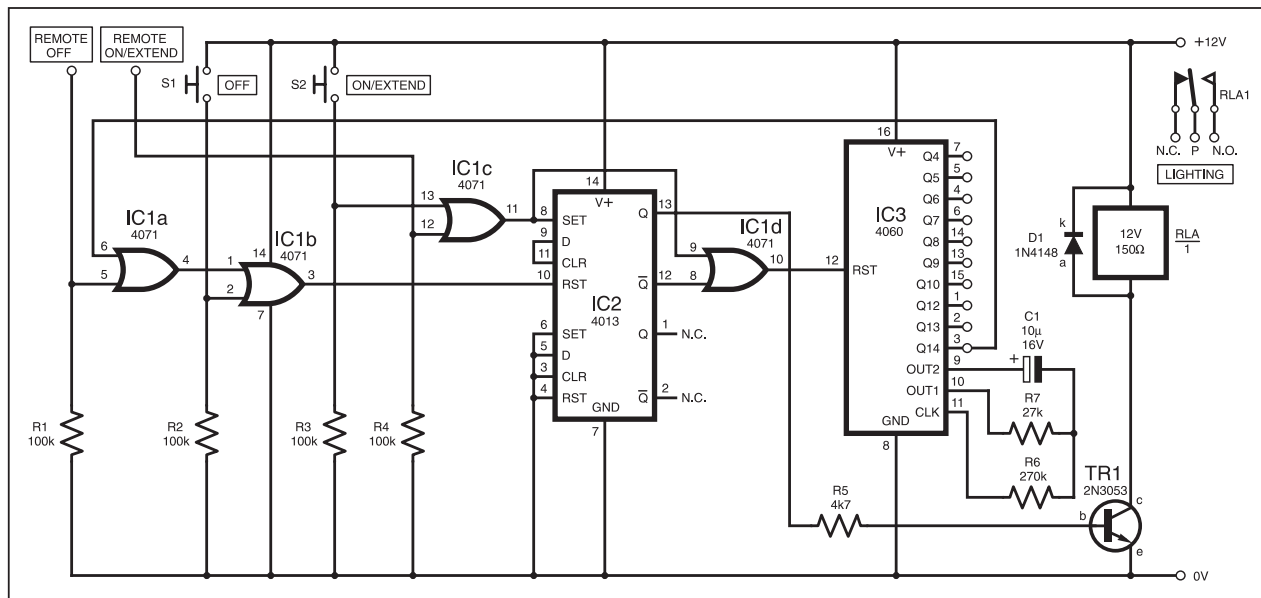


Fig.1. Circuit diagram for a Garden Lighting Controller, with timeout and remote control features.



# SURVEILLANCE

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### HVX400 Mains Powered Room Transmitter

Connects directly to 240V AC supply. Ideal for long-term monitoring. Size 30mm x 35mm, range up to 500m. . . . . **£21.95**

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Smallest kit available. Connects onto telephone line, switches on and off automatically as phone is used. All conversations transmitted. Size 10mm x 20mm, powered from line, up to 500m range. . . . . **£13.95**

### TLX700 Micro-miniature Telephone Transmitter

Best selling kit. Performance as UTLX but easier to assemble as PCB is 20mm x 20mm. . . . . **£14.95**

### STLX High-performance Telephone Transmitter

High-performance transmitter with buffered output for greater stability and range. Connects onto telephone line and switches on and off automatically as phone is used. Both sides of conversation transmitted up to 1000m. Powered from line. Size 22mm x 22mm. . . . **£16.95**

### PTS7 Automatic Telephone Recording Interface

Connects between telephone line (anywhere) and normal cassette recorder. Automatically switches recorder on and off as phone is used. Both sides of any conversation recorded. 9V operation, size 20mm x 67mm. . . . . **£21.95**

### CD400 Pocket Size Bug Detector/Locator

LED and piezo bleeper pulse slowly. Pulse rate and tone pitch increase as signal source is approached. Variable sensitivity allows pinpointing of signal source. 9V operation, size 45mm x 54mm. . . . . **£34.95**

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### QTX180 Crystal Controlled Room Transmitter

Narrow band FM crystal transmitter for ultimate in privacy. Output frequency 173.225 MHz. Designed for use with QRX180 receiver unit. Size 20mm x 67mm, 9V operation, range up to 1000m . . . . . **£44.95**

### QLX180 Crystal Controlled Telephone Transmitter

Specifications as per QTX180 but connects onto telephone line to allow monitoring of both sides of conversations. . . . . **£44.95**

### QSX180 Line Powered Crystal Telephone Transmitter

Connects onto telephone line, switches on and off as phone is used. Power is drawn from line. Output frequency 173.225 MHz. Designed for use with QRX180 receiver. Size 32mm x 37mm. Range up to 500m. . . . . **£39.95**

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Specifically designed for use with any of the SUMA 'O' range kits. High sensitivity design. Complex RF front end section supplied as pre-built and aligned sub-assembly so no difficult setting up. Headphone output. PCB size 60mm x 75mm. 9V operation. . . . . **£69.95**

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Connects to headphone socket of CD player, Walkman or Hi-Fi and broadcasts your favourite music around house and garden up to 250m. Size 27mm x 60mm, 9V operation. . . . . **£22.95**

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# Everyday Practical Electronics are pleased to be able to offer all readers these **ELECTRONICS CD-ROMS**

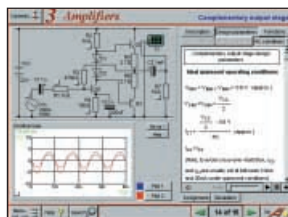
## ELECTRONICS PROJECTS



Logic Probe testing

*Electronic Projects* is split into two main sections: **Building Electronic Projects** contains comprehensive information about the components, tools and techniques used in developing projects from initial concept through to final circuit board production. Extensive use is made of video presentations showing soldering and construction techniques. The second section contains a set of ten projects for students to build, ranging from simple sensor circuits through to power amplifiers. A shareware version of Matrix's CADPACK **schematic capture, circuit simulation and p.c.b. design** software is included. The projects on the CD-ROM are: Logic Probe; Light, Heat and Moisture Sensor; NE555 Timer; Egg Timer; Dice Machine; Bike Alarm; Stereo Mixer; Power Amplifier; Sound Activated Switch; Reaction Tester. Full parts lists, schematics and p.c.b. layouts are included on the CD-ROM.

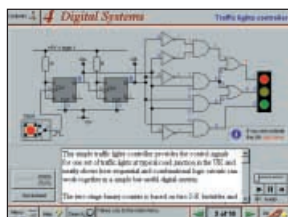
## ANALOGUE ELECTRONICS



Complimentary output stage

*Analogue Electronics* is a complete learning resource for this most difficult branch of electronics. The CD-ROM includes a host of virtual laboratories, animations, diagrams, photographs and text as well as a SPICE electronic circuit simulator with over 50 pre-designed circuits. Sections on the CD-ROM include: **Fundamentals** – Analogue Signals (5 sections), Transistors (4 sections), Waveshaping Circuits (6 sections). **Op.Amps** – 17 sections covering everything from Symbols and Signal Connections to Differentiators. **Amplifiers** – Single Stage Amplifiers (8 sections), Multi-stage Amplifiers (3 sections). **Filters** – Passive Filters (10 sections), Phase Shifting Networks (4 sections), Active Filters (6 sections). **Oscillators** – 6 sections from Positive Feedback to Crystal Oscillators. **Systems** – 12 sections from Audio Pre-Amplifiers to 8-Bit ADC plus a gallery showing representative p.c.b. photos.

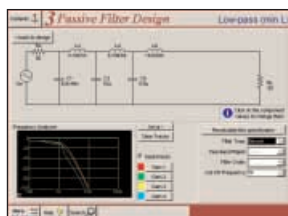
## DIGITAL ELECTRONICS



Virtual laboratory – Traffic Lights

*Digital Electronics* builds on the knowledge of logic gates covered in *Electronic Circuits & Components* (opposite), and takes users through the subject of digital electronics up to the operation and architecture of microprocessors. The virtual laboratories allow users to operate many circuits on screen. Covers binary and hexadecimal numbering systems, ASCII, basic logic gates, monostable action and circuits, and bistables – including JK and D-type flip-flops. Multiple gate circuits, equivalent logic functions and specialised logic functions. Introduces sequential logic including clocks and clock circuitry, counters, binary coded decimal and shift registers. A/D and D/A converters, traffic light controllers, memories and microprocessors – architecture, bus systems and their arithmetic logic units.

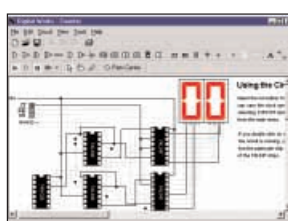
## FILTERS



Filter synthesis

*Filters* is a complete course in designing active and passive filters that makes use of highly interactive virtual laboratories and simulations to explain how filters are designed. It is split into five chapters: **Revision** which provides underpinning knowledge required for those who need to design filters. **Filter Basics** which is a course in terminology and filter characterization, important classes of filter, filter order, filter impedance and impedance matching, and effects of different filter types. **Advanced Theory** which covers the use of filter tables, mathematics behind filter design, and an explanation of the design of active filters. **Passive Filter Design** which includes an expert system and filter synthesis tool for the design of low-pass, high-pass, band-pass, and band-stop Bessel, Butterworth and Chebyshev ladder filters. **Active Filter Design** which includes an expert system and filter synthesis tool for the design of low-pass, high-pass, band-pass, and band-stop Bessel, Butterworth and Chebyshev op.amp filters.

## DIGITAL WORKS 3.0



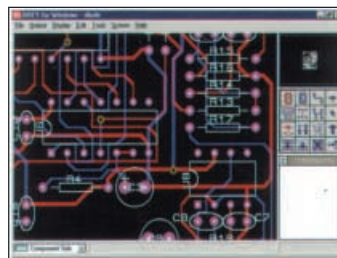
Counter project

*Digital Works Version 3.0* is a graphical design tool that enables you to construct digital logic circuits and analyze their behaviour. It is so simple to use that it will take you less than 10 minutes to make your first digital design. It is so powerful that you will never outgrow its capability.

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- Easy-to-use digital interface
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- Vast library of logic macros and 74 series i.c.s with data sheets
- Powerful tool for designing and learning

## ELECTRONICS CAD PACK

NEW



PCB Layout

Electronics CADPACK allows users to design complex circuit schematics, to view circuit animations using a unique SPICE-based simulation tool, and to design printed circuit boards. CADPACK is made up of three separate software modules: **ISIS Lite** which provides full schematic drawing features including full control of drawing appearance, automatic wire routing, and over 6,000 parts. **PROSPICE Lite** (integrated into ISIS Lite) which uses unique animation to show the operation of any circuit with mouse-operated switches, pots, etc. The animation is compiled using a full mixed mode SPICE simulator. **ARES Lite** PCB layout software allows professional quality PCBs to be designed and includes advanced features such as 16-layer boards, SMT components, and even a **fully functional autorouter**.

## “C” FOR PICMICRO MICROCONTROLLERS

NEW



C for PICmicro Microcontrollers is designed for students and professionals who need to learn how to use C to program embedded microcontrollers. This product contains a complete course in C that makes use of a virtual C PICmicro which allows students to see code execution step-by-step. Tutorials, exercises and practical projects are included to allow students to test their C programming capabilities. Also includes a complete Integrated Development Environment, a full C compiler, Arizona Microchip's MPLAB assembler, and software that will program a PIC16F84 via the parallel printer port on your PC. (Can be used with the *PICtutor* hardware – see opposite.)

Although the course focuses on the use of the PICmicro series of microcontrollers, this product will provide a relevant background in C programming for any microcontroller.

## PRICES

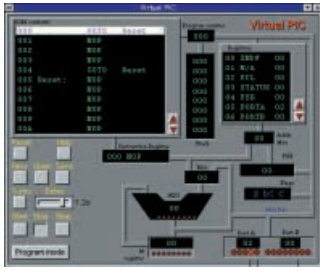
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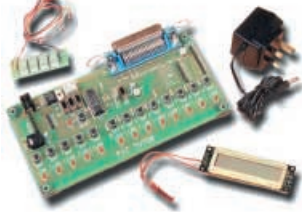
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## Interested in programming PIC microcontrollers? Learn with **PICtutor** by John Becker



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Nearly 40 Tutorials cover virtually every aspect of PIC programming in an easy to follow logical sequence.

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Minimum system requirements for these CD-ROMs: PC with 486/166MHz, VGA+256 colours, CD-ROM drive, 32MB RAM, 10MB hard disk space. Windows 95/98, mouse, sound card, web browser.

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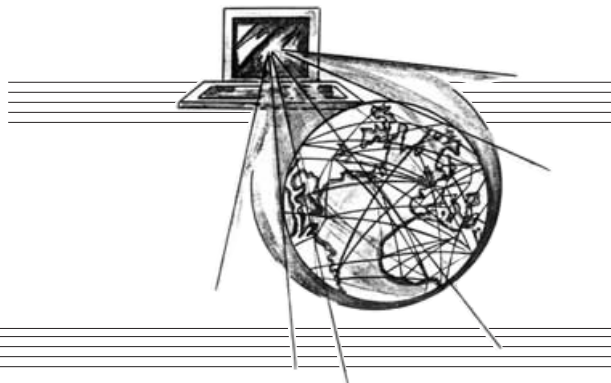
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## A Tasty Dish

A RECENT TV programme followed the progress of a number of trainee chefs as they passed through a training school. The tutor demonstrated how to turn out a certain dish which the students had to re-create as accurately as possible in the allotted time. If it didn't quite look as they intended, they were told, it didn't matter too much because the customer would never know what the "proper" dish was supposed to look like anyway!

I thought that this principle could apply to web design. Each web browser has its own peculiarities in the way it can handle cascading style sheets, tables, text, Javascript and more besides. A web site optimised for one browser can look a mess in another, or on another system. It is possible to use browser-sniffing scripts to detect the type of browser being used, and direct the user to a suitable version of the site developed for his web browser, but running several versions of a site just adds to the cost of its design and development.

A more realistic approach is to make the site look reasonably "accurate" when viewed in any of the popular browsers on popular platforms, and also try to design for a certain screen resolution, also being mindful of any functionality needed (cookies, secure ordering, Javascript and so on). If a web site designer aims for a middle ground, then there is a good chance that most of the users looking in will see an acceptable version of the "dish", especially as they will probably never know what the dish was supposed to look like anyway.

I sometimes check the web site statistics of my client sites, and I can say that anything from 65 per cent up to 95 per cent of people use Microsoft Internet Explorer 5. The rest use Netscape Navigator, Opera or a small number of specialist text-based browsers.

## Netscape 6.0

Netscape's latest incarnation of its web browser is now available for download from their website at [www.netscape.com](http://www.netscape.com). Netscape 6 has been completely rebuilt from the ground up, and uses Netscape's "Gecko" engine, so by rights it's a Version One browser, rather than a Version Six upgrade. It has been coded on an open-source basis. "Netscape 6 is the most standards-compliant browser ever released. It is the first browser to deliver the robust, consistent, cross-platform web standards support that developers have been demanding. It supports more web standards, more deeply, more consistently across platforms than any other browser, and it's being released simultaneously on Windows, Macintosh, and Linux" says Netscape's web site.

This standards compliance will come as a novelty to many designers, who, like myself, have become accustomed to adapting, scrapping and rewriting code to make it work properly in all the popular browsers. In practice, the striving for compliance is a double-edged sword though.

Not every web user will want to persevere with a download in excess of 20MB from Netscape's site: the first stage downloads a small installer program after which various options can be selected to customise the download. You can also choose the more sensible option of downloading the re-installation files themselves, rather than letting Netscape try to upgrade your system "on the fly".

## Installation Snags Overcome

I downloaded the 23MB needed to install Navigator 6. The file transfer went flawlessly but worryingly, it wanted to de-install my existing version of Netscape Navigator first, until I realised it actually referred to my beta version of Netscape 6 and not my older Navigator 4.6. Then the installation routine stalled completely, forcing me to reboot. Nevertheless the installation process was completed properly afterwards, and soon I was pointing Netscape's new browser towards various web sites.

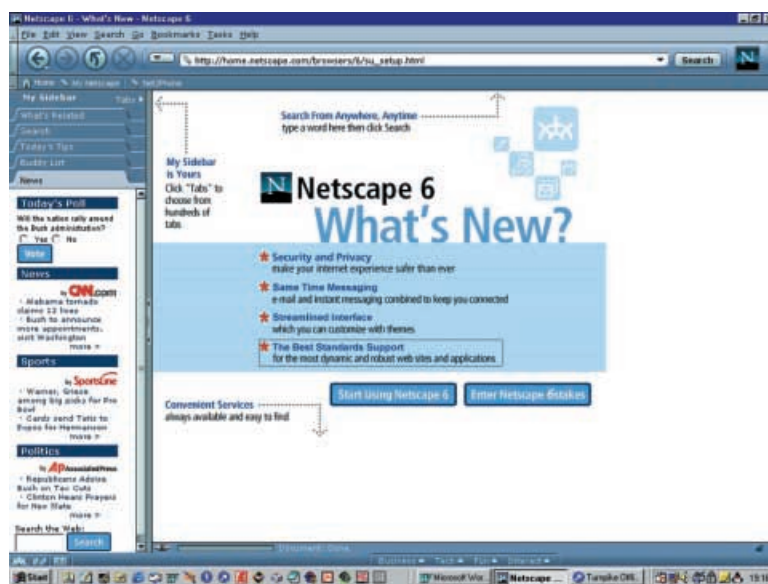
The first thing I noticed was that it was somewhat slow to launch, but before long I was greeted with a stylish window and a multitude of navigation bars. Version 6 has configurable "skins" or themes to adapt the appearance, or you can revert to the classic Navigator style instead. A neat draggable sidebar can be selected to fill with your choice of channels when you go online, and it has a built-in Buddy List to keep track of friends when on-line, and links to enable Net2Phone to be downloaded. Furthermore, it imports Internet Explorer Favorites immediately, a welcome feature. Many other features are available in the configurable sidebar.

More problematic for designers, though, is that some current web pages were broken up when viewed in Navigator 6. Some

Javascripted functions failed to function properly and "sliced" images – which are arranged in tables – were sometimes broken up; furthermore the new browser doesn't support certain functions whatsoever.

If the pages have been coded to obey the rules, then in theory there shouldn't be a problem, yet until now designers have had to work with web browsers that have not been entirely compliant: now having made web sites compatible with older browsers, we must agonise over the more strict rules-obedience of Navigator 6 instead.

The challenge now is to code all pages precisely in accordance with published HTML standards, and also make everything backwards-compatible for the older generations of web browsers as well. The hope is that ultimately we can eventually dump our legacy web browsers and move onto something which is stable, predictable and compliant, and in this respect Netscape 6 is a welcome move in the right direction. If only it had happened five years ago.



We can supply back issues of *EPE* by post, most issues from the past five years are available. An *EPE* index for the last five years is also available – see order form. Alternatively, indexes are published in the December issue for that year. Where we are unable to provide a back issue a photostat of any *one article* (or *one part* of a series) can be purchased for the same price. Issues from July 2000 onwards are also available to download from [www.epemag.com](http://www.epemag.com).

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# THE SCHMITT TRIGGER

ANTHONY H. SMITH

Part 4

*In this short series, we investigate the Schmitt trigger's operation; explore the various ways of implementing its special characteristics and also look at how we can use it to create oscillators and pulse width modulators.*

## Astable, PWM, Triangle Waveforms, Transducer Interface

**L**AST month, in Part Three of this series, we saw how the Schmitt trigger can be used as the central element in monostable and bistable multivibrator circuits. This month, we'll look at the third member of the multivibrator family, the *astable* multivibrator, and we'll see how it can be adapted to form a pulse width modulator. We'll also examine the use of hysteresis in generating triangle waves, and we'll investigate the Schmitt's important role as an interface for sensor devices.

### TIME FOR SOME RELAXATION . . .

Both the monostable and bistable multivibrators examined last month have at least one stable state, i.e., they remain in a constant, stable state until "triggered" by an external signal. The *astable* multi-vibrator, on the other hand, has no stable state: the circuit alternates from one state to another, and continues to *oscillate* without need of any external trigger signals.

The astable falls into a class of oscillators known as *relaxation* oscillators, circuits in which the voltages or currents change suddenly at least once during each cycle. The circuit diagram of a simple, dual-rail astable, using the LF351 op.amp as a comparator, is shown in Fig.4.1a. Note how the circuit has both positive feedback (essential to the Schmitt trigger function), and negative feedback applied via resistor R3. We can understand how the astable works by referring to the circuit waveforms in Fig.4.1b.

Assume that IC1's output voltage,  $V_{OUT}$ , is at its positive saturation level,  $V_{SAT+}$ . The potential  $V+$  at the non-inverting input (pin 3) will sit at a positive level defined by  $V_{SAT+}$ , resistor R1 and R2. This is the *upper threshold* voltage,  $V_{TU}$ . During the period  $T_1$ , the voltage  $V_{C1}$  on timing capacitor C1 will increase, exponentially, in a positive direction as C1 is charged via timing resistor R3.

### . . . AND REGENERATION

Eventually, when  $V_{C1}$  just exceeds  $V_{TU}$ , the comparator "trips" and  $V_{OUT}$  starts to go negative. The positive feedback provided by resistor R2 provides the familiar *regenerative* action which ensures that  $V_{OUT}$  rapidly traverses from positive saturation to negative saturation, denoted  $V_{SAT-}$ .

During period  $T_2$ ,  $V_{C1}$  starts to decrease as capacitor C1's electric field begins to "relax" and the energy stored in it starts to dissipate. However, the process does not stop when the voltage on capacitor C1 reaches zero; instead,  $V_{C1}$  becomes increasingly negative as C1 charges toward  $V_{SAT-}$ .

During this time, the non-inverting input voltage,  $V+$ , sits at a negative level,  $V_{TL}$ , the *lower threshold* voltage. When the *negative* voltage on C1 just exceeds  $V_{TL}$ , the comparator trips again and  $V_{OUT}$  rapidly returns to its positive saturation level,  $V_{SAT+}$ . The process now repeats, and  $V_{OUT}$  alternates between its

two, *unstable* states at a frequency determined by capacitor C1 and resistor R3.

Essentially, the circuit is simply a dual-rail, inverting Schmitt trigger with thresholds set by resistors R1 and R2 as described in Part Two of this series:

$$V_{TU} = \frac{R1 \times V_{SAT+}}{R1 + R2} \text{ (volts)}, \quad \text{and:} \quad V_{TL} = \frac{R1 \times V_{SAT-}}{R1 + R2} \text{ (volts)}$$

However, the circuit effectively provides its own input in the form of the exponentially varying voltage on C1. The "mark" and "space" time periods,  $T_1$  and  $T_2$ , are given by:

$$T_1 = \tau \ln \left\{ \frac{V_{SAT+} - V_{TL}}{V_{SAT+} - V_{TU}} \right\} \text{ (seconds)},$$

$$\text{and: } T_2 = \tau \ln \left\{ \frac{V_{SAT-} - V_{TU}}{V_{SAT-} - V_{TL}} \right\} \text{ (seconds)},$$

where the *time constant*  $\tau = (C1 \times R3)$  (seconds), and  $\ln$  represents the natural logarithm.

### ASYMMETRICAL OUTPUT LEVELS

The circuit was built using the component values as shown in Fig.4.1a. With the supply rails set to  $+V_S = +5V$  and  $-V_S = -5V$ , the output saturation levels were found to be  $V_{SAT+} = +4.20V$  and  $V_{SAT-} = -3.65V$ . Using the equations given above, the thresholds should be  $V_{TU} = +0.979V$  and  $V_{TL} = -0.850V$ . The actual values, measured by observing the voltage levels at the non-inverting input (pin 3), were  $V_{TU} = +0.98V$  and  $V_{TL} = -0.86V$ .

With  $C1 = 3.3nF$  and  $R3 = 100k\Omega$ ,  $\tau = 0.33ms$ . Therefore, using the measured values for  $V_{SAT+}$ ,  $V_{SAT-}$ ,  $V_{TU}$  and  $V_{TL}$ , the equations for periods  $T_1$  and  $T_2$  yield values of  $149\mu s$  and  $167\mu s$ , respectively.

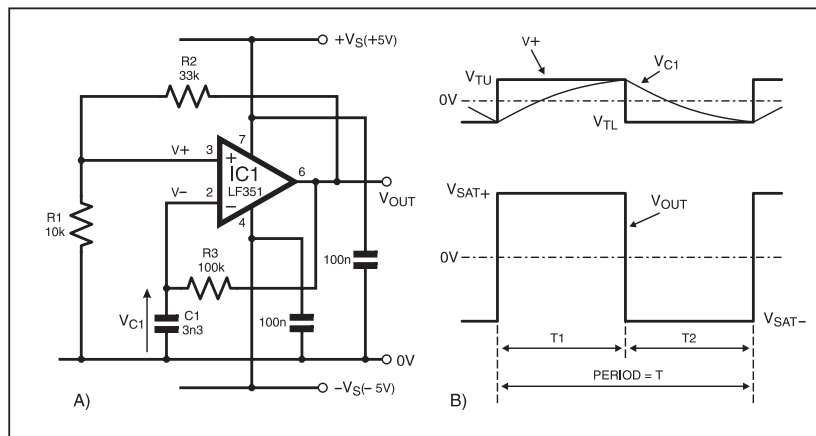


Fig.4.1(a). Astable multivibrator based on a Schmitt trigger and (b) circuit waveforms.

The measured values were  $T_1 = 144\mu\text{s}$  and  $T_2 = 160\mu\text{s}$ . The fact that  $T_1$  does not equal  $T_2$  is due to the asymmetry in the output saturation levels, which also results in the magnitude of the thresholds being unequal. Whether or not this unequal *mark-space ratio* is a problem depends entirely on the application.

## DUTY CYCLE

The mark-space ratio of a rectangular waveform is more properly expressed in terms of *duty cycle*, where:

$$\text{Duty Cycle} = \frac{T_1}{T_1 + T_2} \times 100\%$$

In the above case, we see that the output duty cycle is  $144\mu\text{s}/(144\mu\text{s} + 160\mu\text{s}) = 47.4\%$ . If we can adapt the circuit such that  $V_{\text{SAT}+} = -V_{\text{SAT}-}$ , and hence  $V_{\text{TU}} = -V_{\text{TL}}$ , we find that:

$$T_1 = T_2 = \tau \ln \left\{ \frac{V_{\text{SAT}+} + V_{\text{TU}}}{V_{\text{SAT}+} - V_{\text{TU}}} \right\} \text{ (seconds)}$$

resulting in a 50% duty cycle.

One way to achieve this is to use an op.amp with “rail-to-rail” output swing, whereby  $V_{\text{OUT}}$  swings to within a few millivolts of each supply rail. Provided IC1’s output is lightly loaded and the magnitudes of the supply rails are equal, this approach ensures that  $|V_{\text{SAT}+}| = |V_{\text{SAT}-}|$ . If a rail-to-rail op.amp is not available, consider the use of output “clamping” using back-to-back Zener diodes or a diode bridge arrangement, both of which were described in Part Two.

The astable’s oscillation frequency is given by

$$\text{Frequency, } f = 1/T$$

where  $T$  is the period of the output cycle. Since  $T = T_1 + T_2$ , it follows that when  $T_1 = T_2$ , the frequency is simply  $f = 1/(2 \times T_1)$ , and can be found from:

$$\text{Frequency, } f = \frac{1}{2\tau \ln \left\{ \frac{V_{\text{SAT}+} + V_{\text{TU}}}{V_{\text{SAT}+} - V_{\text{TU}}} \right\}} \text{ (Hz)}$$

Clearly, the frequency can be increased either by reducing  $\tau$ , or by decreasing the size of the threshold voltages. More about this later.

## CHOICE OF OP.AMP

The LF351 is a good choice of op.amp for use in multivibrators like the one in Fig.4.1. Although it does not provide “rail-to-rail” performance, it is a reasonably fast device with good slew rate (typically  $13\text{V}/\mu\text{s}$ ), and its j.f.e.t. input stage results in very low input bias currents.

With capacitor  $C_1 = 3.3\text{nF}$  and resistor  $R_3 = 100\text{k}\Omega$ , the circuit produced a well-shaped rectangular output at just over  $3\text{kHz}$ . Reducing  $R_3$  to  $10\text{k}\Omega$  increased the frequency to just under  $30\text{kHz}$ , and although the output shape was still good, the measured values of  $T_1$  and  $T_2$  were somewhat different from the calculated values due to changes in the thresholds resulting from the effects of finite bandwidth.

Reducing  $C_1$  to  $330\text{pF}$  increased the frequency to  $150\text{kHz}$ , although the edges of the output waveform were noticeably sloped. With  $C_1 = 100\text{pF}$ , the frequency was just over  $300\text{kHz}$ , but the output waveshape was now “trapezoidal”. Although the LF351 has a *unity-gain* bandwidth of around  $4\text{MHz}$ , its ability to generate “sharp” square waves at frequencies above  $100\text{kHz}$  is limited by the effects of finite slew-rate.

## LOW FREQUENCIES

Generating low frequency waveforms requires a large time constant. To some degree, this can be achieved by maximising capacitor  $C_1$ , although for a *bipolar* astable like the one in Fig.4.1, where  $V_{\text{C}_1}$  swings both positive and negative,  $C_1$  must be a non-polarised type, which limits the maximum capacitance available. (Although large-value, non-polarised electrolytic capacitors are available, they often have relatively large leakage currents which can affect the circuit’s operation quite considerably).

At first sight, selecting a large value for resistor  $R_3$  would appear to be the simplest way of maximising  $\tau$ , especially as resistance values up to  $10\text{M}\Omega$  are readily available. However, the effects of input bias current,  $I_{\text{B}}$ , flowing into (or out of) the inverting input should not be ignored, especially where accurate control of frequency and duty cycle are required.

For example, let’s say we built the astable using an op.amp with an input bias current of around  $200\text{nA}$  (not uncommon for devices like the LM358 or 741). When  $R_3$  is small ( $<100\text{k}\Omega$ ), the bias current has negligible effect on the charging and discharging of  $C_1$ . However, when  $R_3$  is in the region of  $1\text{M}\Omega$  or more, the input bias current becomes relatively large compared to the current flowing through  $R_3$ , and effectively “unbalances” the charging action. (The capacitor leakage currents mentioned above can have a similar effect). Although this will not stop the astable oscillating, it can have a marked effect on duty cycle and frequency.

Fortunately, the LF351’s very low input bias current (typically just  $50\text{pA}$  at room temperature) permits the use of large values for resistor  $R_3$  with little effect on performance. For instance, with  $C_1 = 1\mu\text{F}$  (non-polarised) and  $R_3 = 1\text{M}\Omega$ , the circuit of Fig.4.1 produced a square wave with period  $T = 0.954\text{s}$  and pulse width  $T_1 = 0.449\text{s}$ . At 47%, the duty cycle was just short of the 50% needed for a perfectly “symmetrical” square wave, but this was due to the unequal magnitudes of  $V_{\text{SAT}+}$  and  $V_{\text{SAT}-}$ , not to the effects of input bias current.

## COMMON MODE INPUT RANGE

The LF351 is just one of many op.amps available with low input bias currents. Other devices with low  $I_{\text{B}}$  are the Harris/Intersil CA3140 (single;  $I_{\text{B}} = 10\text{pA}$  typ.); the National Semiconductor LMC662 (dual;  $I_{\text{B}} = 0.002\text{pA}$  typ.); the Motorola MC33182 (dual;  $I_{\text{B}} = 30\text{pA}$  typ.); and the Texas Instruments TLC27L2 (dual;  $I_{\text{B}} = 0.7\text{pA}$  typ.). There are many others to choose from.

Another important input parameter that should not be overlooked when designing any op.amp or comparator circuit is the *common mode input voltage range*. As we saw in Part Two, the common mode input voltage range defines the allowable input voltage that can be tolerated by the device without malfunction.

When operating on  $\pm 5\text{V}$  supplies, the LF351’s common mode range is typically  $+5\text{V}$ ,  $-2\text{V}$ . Therefore, resistors  $R_1$  and  $R_2$  (Fig.4.1) should be selected to ensure that the voltage,  $V_+$ , at the non-inverting input (pin 3) terminal (and, hence, at the inverting input (pin 2)) cannot go outside this range, otherwise the op.amp might not function properly. With  $R_1 = 10\text{k}\Omega$  and  $R_2 = 33\text{k}\Omega$ ,  $V_+$  will not exceed  $\pm 1.2\text{V}$  even if  $V_{\text{OUT}}$  swings as much as  $\pm 5\text{V}$ .

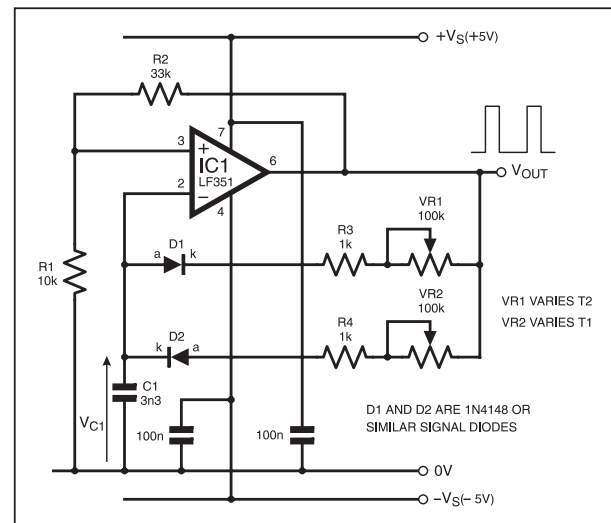


Fig.4.2. Circuit modifications to the astable results in a Variable Width Pulse Generator.

## VARIABLE PULSE GENERATOR

The simple astable of Fig.4.1 can easily be adapted to produce a rectangular output with widely variable duty cycle. The required modifications are shown in the circuit diagram Fig.4.2, where  $R_3$  has been replaced by the diode/resistor network comprising  $D_1$ ,  $D_2$ ,  $R_3$ ,  $R_4$ ,  $VR_1$  and  $VR_2$ .

The presence of the diodes allows capacitor  $C_1$  to be charged and discharged at different rates. For example, when  $V_{\text{OUT}}$  is high (at  $V_{\text{SAT}+}$ ),  $C_1$  charges via  $D_2$ ,  $R_4$  and potentiometer  $VR_2$ . Diode  $D_1$  is reverse biased, so only  $R_4$  and  $VR_2$  control the charging current flowing into  $C_1$ , and hence determine the width of the time period  $T_1$ .

When  $V_{\text{OUT}}$  goes low (to  $V_{\text{SAT}-}$ ),  $D_2$  becomes reverse biased and  $C_1$  discharges via  $D_1$ ,  $R_3$  and  $VR_1$ . Consequently,  $R_3$  and  $VR_1$  now dictate the rate of discharge, and hence control the width of  $T_2$ .

Typical waveforms generated by the Variable Width Pulse Generator circuit are shown in Fig.4.3, obtained with  $C1 = 3.3\text{nF}$ ,  $R3$  plus  $VR1 = 30\text{k}\Omega$ , and  $R4$  plus  $VR2 = 10\text{k}\Omega$ . The exponential waveform,  $V_{C1}$ , shows how capacitor  $C1$  charges rapidly and then discharges relatively slowly, resulting in  $T1 = 18.8\mu\text{s}$  and  $T2 = 59.2\mu\text{s}$ .

Potentiometers  $VR1$  and  $VR2$  provide independent control of  $T1$  and  $T2$ , and with the values shown allow the duty cycle to be varied from around 1.5% to 98.5%. By switching in different values of  $C1$ , say in decade ranges from  $1\text{nF}$  to  $10\mu\text{F}$ , the circuit is capable of producing pulse widths ranging from around  $1\mu\text{s}$  to over half a second.

## SINGLE RAIL ASTABLE

A single rail version of the astable multivibrator is shown in Fig.4.4. Using an op.amp like the TS902 having rail-to-rail input and output swings simplifies the design procedure. Provided the output is not heavily loaded,  $V_{OUT}$  will swing from  $0\text{V}$  to  $+V_S$ , removing any ambiguity about the values of  $V_{SAT-}$  and  $V_{SAT+}$ . Furthermore, there is no need to worry about the input signals,  $V+$  and  $V-$ , straying outside the common mode input voltage range.

Since  $V_{OUT}$  swings rail-to-rail, we can assume that  $V_{SAT-} = 0\text{V}$  and  $V_{SAT+} = +V_S$ , and making these substitutions in the equations for  $T1$  and  $T2$  quoted previously for the dual-rail astable, we find that:

$$T1 = \tau \ln \left\{ \frac{+V_S - V_{TL}}{+V_S - V_{TU}} \right\} \quad (\text{seconds})$$

$$\text{and: } T2 = \tau \ln \left\{ \frac{V_{TU}}{V_{TL}} \right\} \quad (\text{seconds})$$

where the time constant  $\tau = (C1 \times R3)$  (seconds).

Since the circuit is basically an adaptation of the single rail Schmitt trigger described in Part Two, the threshold voltages,  $V_{TU}$  and  $V_{TL}$  are given by:

$$\text{Upper Threshold Voltage, } V_{TU} = \frac{(V_{REF} \times R2) + (+V_S \times R_{TH})}{R_{TH} + R2} \quad (\text{volts})$$

$$\text{and: Lower Threshold Voltage, } V_{TL} = \frac{(V_{REF} \times R2)}{R_{TH} + R2} \quad (\text{volts})$$

where  $R_{TH}$  is the Thévenin equivalent resistance of the  $R1a$ - $R1b$  potential divider:

$$R_{TH} = \frac{R1a \times R1b}{R1a + R1b} \quad (\text{ohms})$$

and  $V_{REF}$  is the reference voltage generated by the potential divider  $R1a$ - $R1b$  and the positive supply:

$$V_{REF} = \frac{+V_S \times R1b}{R1a + R1b} \quad (\text{volts})$$

Introducing  $R_{TH}$  and  $V_{REF}$  allows us to represent the single rail astable with its equivalent circuit shown in Fig.4.5a. We will consider the equivalent circuit in more detail, shortly. First, we'll examine the performance of the Single Rail Astable with voltage follower circuit – shown in Fig.4.4.

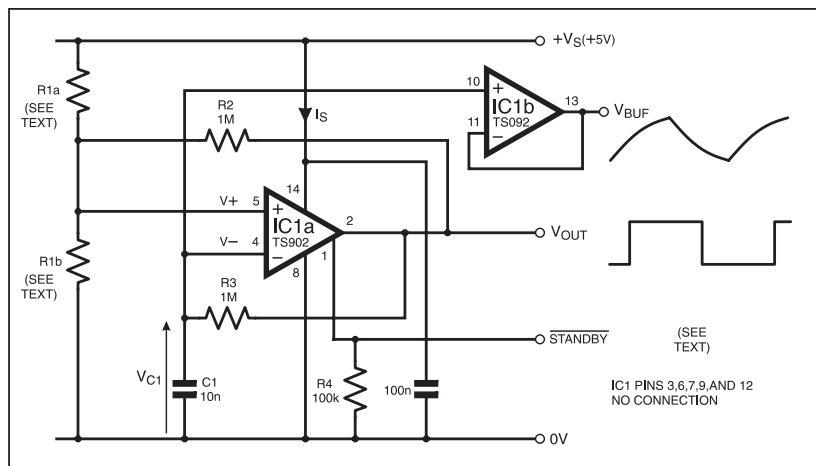


Fig.4.4. Circuit diagram for a Single-Rail Astable with voltage follower.

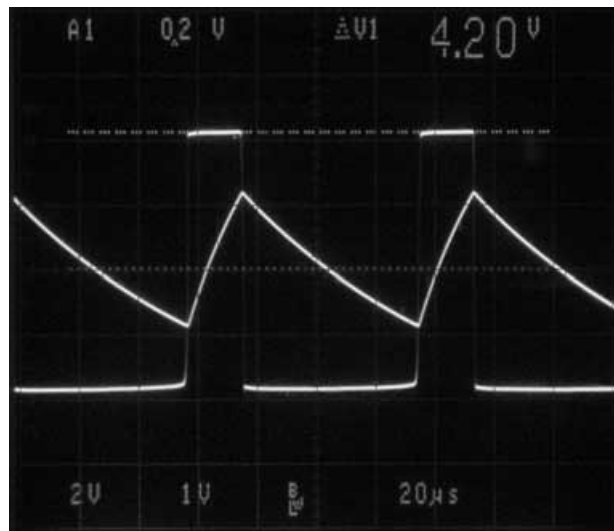


Fig.4.3. Pulse Generator Waveforms. Pulse waveform is  $V_{OUT}$  (2V/div.). Exponential waveform is timing capacitor voltage,  $V_{C1}$  (1V/div.). Timebase:  $20\mu\text{s}/\text{div}$ .

## POWER SAVING

Although not exceptionally fast (the slew rate is typically  $0.8\text{V}/\mu\text{s}$ ), the STMicroelectronics TS902 has very low input bias current ( $I_B = 1\text{pA}$  typ.) which, as we have seen, is important when using large resistance values. It also features a "standby" function, whereby its current consumption can be reduced to a minimal level to save power. More about this later.

Since the resistance values in Fig.4.4 are large, it is important not to "load" the circuit nodes when probing the waveforms. Even using a 'scope probe with a  $10\text{M}\Omega$  input impedance would significantly load the op.amp inputs and would affect the astable's operation.

This can be avoided by connecting the second half of the dual TS902 as a voltage follower (IC1b) which "buffers" the sensitive nodes. By connecting the follower to either of IC1a's inputs, the threshold levels and exponential waveform can be observed by connecting the 'scope probe to IC1b's low-impedance output. Note, however, that the signals will be "shifted" by IC1b's input offset voltage, which can be as much as  $\pm 10\text{mV}$ .

## CIRCUIT PERFORMANCE

Initially, the Single Rail Astable (Fig.4.4) circuit was built with  $R1a = R1b = 200\text{k}\Omega$ . With  $C1 = 10\text{nF}$  and  $R3 = 1\text{M}\Omega$ , the time constant  $\tau = 10\text{ms}$ . With  $+V_S = +5\text{V}$ , the theoretical values of  $T1$  and  $T2$  calculated using the equations earlier are  $T1 = 1.82\text{ms}$  and  $T2 = 1.82\text{ms}$ . The actual, measured values were  $T1 = 1.90\text{ms}$  and  $T2 = 1.91\text{ms}$ , equivalent to a duty cycle of 49.9%.

Next, with  $R1a = 150\text{k}\Omega$  and  $R1b = 300\text{k}\Omega$ , the measured values were  $T1 = 2.75\text{ms}$  and  $T2 = 1.47\text{ms}$ , corresponding to a duty cycle of 65.2%. The calculated values are  $T1 = 2.63\text{ms}$  and  $T2 = 1.40\text{ms}$ .

Finally, with  $R1a = 300\text{k}\Omega$  and  $R1b = 150\text{k}\Omega$ , the measured values were  $T1 = 1.45\text{ms}$  and  $T2 = 2.75\text{ms}$ , corresponding to a duty cycle of 34.5%. The calculated values are  $T1 = 1.40\text{ms}$  and  $T2 = 2.63\text{ms}$ .

Clearly, the measured results are in close agreement with the theoretical values. However, it is the variation in duty cycle which is most interesting. For the case where resistors  $R1a$  and  $R1b$  have equal values of  $200\text{k}\Omega$ , the equivalent value of  $V_{REF}$  was  $2.5\text{V}$ , i.e., 50% of  $+V_S$ , and the duty cycle was 49.9%.

When  $R1a = 150\text{k}\Omega$  and  $R1b = 300\text{k}\Omega$ , the equivalent value of  $V_{REF}$  was  $3.333\text{V}$ , i.e., 66.7% of  $+V_S$ , and the duty cycle was 65.2%. Lastly, when  $R1a = 300\text{k}\Omega$  and  $R1b = 150\text{k}\Omega$ , the equivalent value of  $V_{REF}$  was  $1.667\text{V}$ , i.e., 33.3% of  $+V_S$ , and the duty cycle was 34.5%.

Notice that for each case the duty cycle varies linearly with  $V_{REF}$  and is almost directly proportional to  $V_{REF}$  as a percentage of  $+V_S$ . Furthermore, the value of  $R_{TH}$  is  $100\text{k}\Omega$  for each case, i.e., only  $V_{REF}$  varies from one case to another, all other values remain constant.



Clearly,  $V_{REF}$  is controlling the duty cycle, an important finding that we'll investigate shortly.

## SUPPLY CURRENT AND FREQUENCY

With resistors R1a and R1b at 200k $\Omega$ , R3 at 1M $\Omega$  and capacitor C1's value changed to 100nF, Fig.4.4's circuit produced an output frequency of 27.5Hz. Decreasing C1 by two decades to 1nF increased the output frequency to 2275Hz, roughly a hundred-fold increase. The upper limit is about 15kHz: at higher frequencies, the output waveform takes on a "trapezoidal" shape because the TS902 does not have the slow rate necessary to produce rectangular waveforms beyond 20kHz.

It is a fact of life that all circuits, whether linear or digital, tend to consume more power at higher operating frequencies; consequently, the supply current is also greater. The predominant reason for this increase is that capacitances, either external to the active device (like C1), or internal (such as junction capacitances), must be charged and discharged every cycle.

Excessive supply current can be a major problem, especially in battery-powered systems where battery life is inversely proportional to power consumption. Clearly, one way to reduce current drain is to use smaller capacitances wherever possible.

For instance, with C1 shorted out to make  $V_{OUT}$  continually high, the average current taken by Fig.4.4's circuit was 222 $\mu$ A. This is the "static" or "quiescent" operating current. Then, with C1 = 1nF and R3 = 1M $\Omega$ , such that  $\tau = 1$ ms, the astable oscillated at 2275Hz and the average supply current was 332 $\mu$ A, an increase of 110 $\mu$ A on the static value.

However, with C1 = 100nF and R3 = 10k $\Omega$  ( $\tau = 1$ ms), the astable again oscillated at 2275Hz but the supply current was 426 $\mu$ A, an increase of 204 $\mu$ A on the static value. Clearly, the increase in current has almost doubled compared to the case above, even though the time constant, and hence the operating frequency, remain the same.

## A DISABLING FEATURE

Another way to reduce the circuit current drain is to switch off any sections that aren't required. In a notebook computer, for example, the processor can "power down" the internal modem when not in use, thereby conserving battery energy. Even in relatively small circuits, switching off any sub-circuit that is not needed will reduce the average power consumption.

The TS902 dual op.amp provides a "standby" feature which makes it easy to reduce current drain. When the  $\overline{STANDBY}$  terminal (pin 1) is high (connected to  $+V_S$ ), the op.amps function normally. However, if  $\overline{STANDBY}$  is pulled low (to 0V), both op.amps in the package are "disabled" and the outputs go to a high impedance state.

The effect on the astable's current consumption is quite dramatic. For instance, with C1 = 100nF and R3 = 10k $\Omega$ , and with  $\overline{STANDBY}$  high (circuit oscillating at 2275Hz), the op.amp supply current,  $I_S$ , was 420 $\mu$ A. However, with  $\overline{STANDBY}$  pulled low, the circuit stopped oscillating and  $I_S$  fell to just 13 $\mu$ A.

## FREQUENCY STABILITY

For precision applications demanding high frequency stability, a crystal-controlled oscillator would be a better choice than the astable of Fig.4.4. Nevertheless, when an op.amp or comparator with rail-to-rail output swing is used, the astable's operating frequency and duty cycle remain remarkably constant with changes in supply voltage.

For example, using one half of the rail-to-rail LMC6762 dual comparator for IC1a, and with C1 = 10nF and R3 = 100k $\Omega$ , the circuit's frequency and duty cycle were measured as 2539Hz and 49.94% with  $+V_S$  at +5V. With  $+V_S$  increased to +15V, the values were 2549Hz and 50.27%. The fact that the frequency and duty cycle changed by less than one per cent is due to a "balancing" effect between the switching thresholds and charging current.

As the supply voltage increases,  $V_{OUT}$ , and hence the charging current into C1, also increase, and so C1 charges and discharges more quickly. However, the increase in  $+V_S$  causes a corresponding increase in hysteresis voltage (the difference between  $V_{TU}$  and  $V_{TL}$ ), such that C1 has "further" to charge and discharge. The net effect is that T1 and T2 remain fairly constant with changes in  $+V_S$ .

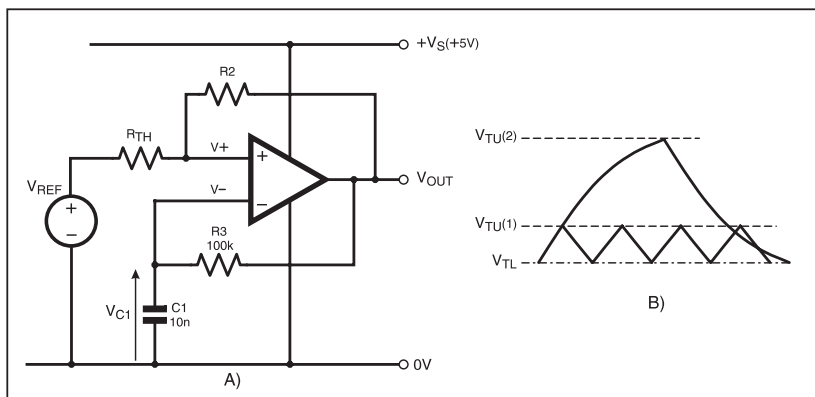


Fig.4.5(a). Equivalent circuit of the single rail astable, and (b) graph showing capacitor charging and discharging between different thresholds.

## PULSE WIDTH MODULATION

We saw how changing the relative values of resistors R1a and R1b effectively varies the value of  $V_{REF}$  and causes a corresponding change in output duty cycle. If we dispense with R1a and R1b and use a voltage source for  $V_{REF}$  as shown in Fig.4.5a,  $V_{REF}$  can then be used to modulate the width of the output pulses.

Waveforms in Fig.4.5b shows C1's voltage,  $V_{C1}$ , when the capacitor charges and discharges between different thresholds. For the case where  $V_{C1}$  starts from  $V_{TL}$  and charges to the relatively large threshold voltage  $V_{TU(2)}$ , the waveform takes on the familiar "exponential" shape. However, if the same capacitor is charged and discharged with the same current over a relatively narrow range from  $V_{TL}$  to  $V_{TU(1)}$ , the waveform is much more "linear" and appears almost triangular.

A circuit that can be built to experiment with the pulse width modulator, where R1 and R2 set the thresholds, and C1 and R3 determine the time constant, is illustrated in Fig.4.6. This part of the circuit is basically the same as that in Fig.4.5a, but with the equivalent resistance  $R_{TH}$  replaced by a real resistor, R1, and with equivalent voltage  $V_{REF}$  replaced by the modulating voltage  $V_{MOD}$ .

Since the difference between  $V_{TU}$  and  $V_{TL}$  is the hysteresis voltage,  $V_H$ , we can ensure that capacitor C1 charges over a narrow range by making resistor R2 much larger than R1 such that  $V_H$  is very small compared to  $V_{OUT}$ . This also results in the average voltage,  $V+$ , at the non-inverting input being approximately equal to  $V_{MOD}$ , that is:  $V+ \approx V_{MOD}$ . Similarly, since  $V_{C1}$  charges between the thresholds established at the non-inverting input, the average voltage,  $V-$ , at the inverting input will also be approximately equal to  $V_{MOD}$ , that is:  $V- \approx V_{MOD}$ .

Therefore, during T1 when  $V_{OUT}$  is at  $V_{SAT+}$ , and C1 is charging via R3, the charging current is simply:  $I_{CHARGE} = (V_{OUT} - V-)/R3$ , or  $I_{CHARGE} = (V_{SAT+} - V_{MOD})/R3$ . Similarly, during T2 when  $V_{OUT}$  is at  $V_{SAT-}$ , and C1 is discharging via R3, the discharging current is simply:  $I_{DISCHARGE} = (V_{SAT-} - V_{MOD})/R3$ . If IC1b has a rail-to-rail output swing, such that  $V_{SAT+} = +V_S$  and  $V_{SAT-} = 0$ , then

$$I_{CHARGE} = (+V_S - V_{MOD})/R3 \text{ and } I_{DISCHARGE} = (-V_{MOD})/R3.$$

Now, the rate of change of voltage on a capacitor is given by:  $\Delta V_C/\Delta t = I/C$ , where  $\Delta V_C$  is the change in voltage,  $\Delta t$  is the time period, I is the current and C is the capacitance. During T1, the voltage on C1 rises from  $V_{TL}$  to  $V_{TU}$ , and so  $\Delta V_C = V_{TU} - V_{TL} = V_H$ . Therefore,  $V_H/T1 = I_{CHARGE}/C1$ . Rearranging and substituting for  $I_{CHARGE}$  we find that:

$$T1 = \frac{V_H \times C1 \times R3}{+V_S - V_{MOD}} \quad (\text{seconds}).$$

Similarly, during T2, the voltage on C1 falls from  $V_{TU}$  to  $V_{TL}$ , and so  $\Delta V_C = V_{TL} - V_{TU} = -V_H$ . Therefore,  $-V_H/T2 = I_{DISCHARGE}/C1$ . Rearranging and substituting for  $I_{DISCHARGE}$  we find that:

$$T2 = \frac{V_H \times C1 \times R3}{V_{MOD}} \quad (\text{seconds}).$$

Now, we saw earlier that

$$\text{Duty Cycle} = \frac{T1}{T1 + T2} \times 100\%,$$

and by substituting for T1 and T2, we find that:

$$\text{Duty Cycle} = \frac{V_{MOD}}{+V_S} \times 100\%.$$

Clearly, the duty cycle is directly proportional to the modulating voltage,  $V_{MOD}$ . The circuit diagram of Fig.4.6 works well with most dual, rail-to-rail op.amps having low input bias current; the STMicroelectronics TS912 and National Semiconductor LMC6482 are good examples. In this circuit, a voltage follower, IC1a, buffers the voltage on VR1's wiper. The buffer is essential to ensure that resistor R1 is driven from a low impedance voltage source. (If a good quality, external d.c. voltage source is available, IC1a can be omitted). IC1b could, of course, be a rail-to-rail comparator, but this would require a separate op.amp to form the voltage follower.

Careful layout and proper decoupling are good practice when "breadboarding" any of the circuits in this series. However, with resistor R1 = 10k $\Omega$  and R2 = 1M $\Omega$ , the hysteresis voltage in Fig.4.6 is only 50mV, and so the slightest noise or interference can introduce significant "jitter" to the output waveform. To minimise these problems, make sure a good quality, "clean" d.c. power supply is used to generate  $+V_S$ . Resistor R4 combined with capacitor C2 form a low-pass filter which removes any mains pickup on potentiometer VR1 wiper, and capacitor C3 (which should be as close as possible to IC1) provides decoupling for the op.amps. A large-value electrolytic capacitor, say 100 $\mu$ F, in parallel with C3 can also help.

## LINEAR RELATIONSHIP

Pulse width modulators can be grouped into two categories: those whose frequency remains constant as duty cycle is varied, and those – like the circuit in Fig.4.6 – where both the duty cycle *and* output frequency vary with  $V_{MOD}$ .

The graphical results obtained using the TS912 dual op.amp for IC1 are shown in Fig.4.7. Notice how the output frequency varies considerably, peaking when  $V_{MOD} = +V_S/2$ , when T1 and T2 are both at a minimum.

It is possible to use op.amps whose input and output voltage swing extends from 0V to some voltage less than  $+V_S$ . For example, tests using the dual LM358 op.amp revealed an output swing from 0V to 3.7V. Therefore,  $V_{MOD}$  would be limited to a maximum of 3.7V, although in practice the limit would be 3.5V since this is the common mode input limit for a supply voltage of +5V. There is still a linear relationship between duty cycle and  $V_{MOD}$ , although duty cycle is now proportional to  $V_{MOD}$  as a fraction of  $V_{SAT+}$  (the positive output saturation voltage), not  $+V_S$ .

Pulse Width Modulation (PWM) is a versatile and widely used function in electronic systems, and finds uses in areas such as motor control, switched mode power supplies and data transmission.

## TRIANGULAR WAVES

Throughout this series we've seen how a *triangular* waveform can be useful when testing the thresholds of a Schmitt trigger, so it's appropriate to describe how a Schmitt trigger can be used as part of a triangle wave generator.

We saw in Fig.4.5b how the exponential voltage waveshape on a capacitor can be made to appear triangular by limiting the range over which the capacitor charges and discharges. This could be achieved using the circuit in Fig.4.4 by making resistor R2 much larger than the parallel combination of resistors R1a and R1b, such that the hysteresis is very small compared to  $+V_S$ . Then, by connecting IC1b as an amplifier rather than as a follower, the small amplitude "pseudo-triangle" on C1 could be increased to a useful magnitude.

The disadvantage of this approach is that the large gain required (in the region of 50 to 100) would lead to problems with noise and offsets, and in any event the output waveshape would never be truly triangular.

## FUNCTION GENERATOR

A more effective approach is shown in Fig.4.8, where a dual op.amp is used to form a non-inverting Schmitt trigger and an *integrator*. These two circuit elements are connected in a closed feedback loop known as a *function generator* where the Schmitt trigger generates a square wave output,  $V_{OUT(SQ)}$ , which forms the input to the integrator, and the integrator generates a triangular output,  $V_{OUT(TRI)}$ , which is fed back to the input of the Schmitt.

Assume that the output of IC1a is in positive saturation, that is:  $V_{OUT(SQ)} = V_{SAT+}$ . This voltage forces a positive current to flow into resistor R3, and since no current flows into IC1b's inverting input (we can ignore the negligible input bias current), all of this current must flow into capacitor C1.

Op.amp IC1b has negative feedback applied via C1; this means that its output will go to whatever voltage is necessary to maintain its inverting input,  $V_-$ , at the same potential as its non-inverting input,  $V_+$ . Since  $V_+$  is at 0V, this means  $V_-$  is forced to equal 0V,

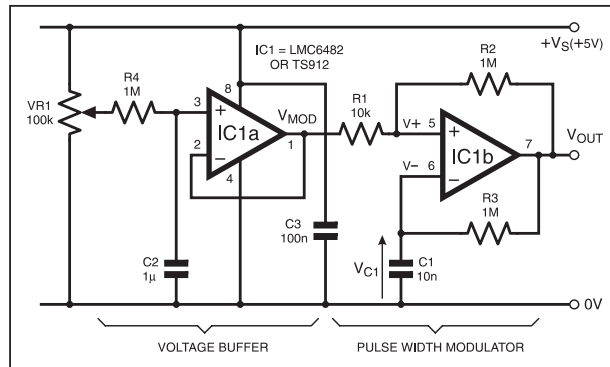


Fig.4.6. Circuit diagram for an experimental Pulse Width Modulator.

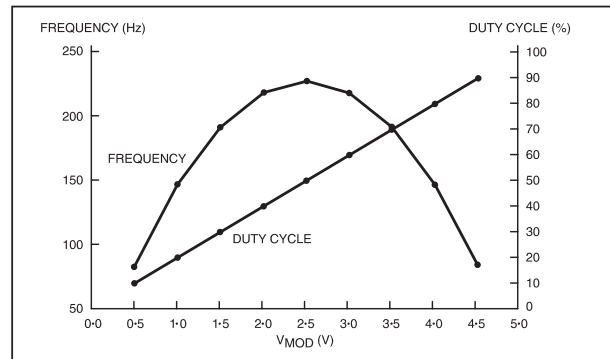


Fig.4.7. Graph showing the output frequency and duty cycle versus modulation voltage for the Pulse Width Modulator circuit using the TS912 op.amp.

also. Therefore, a *constant* current equal to  $V_{SAT+}/R3$  flows into R3 and then into C1.

Now, we saw earlier that when a capacitor is charged by a constant current, its voltage varies *linearly*. Consequently, as the voltage on C1 increases linearly, IC1b's output,  $V_{OUT(TRI)}$ , must ramp linearly in a *negative* direction to maintain  $V_+$  equal to  $V_-$ .

Eventually, when  $V_{OUT(TRI)}$  crosses the Schmitt's lower threshold voltage, IC1a's output goes from positive to negative saturation, that is  $V_{OUT(SQ)} = V_{SAT-}$ . This results in a constant, *negative* current equal to  $V_{SAT-}/R3$  flowing into R3 and C1. Consequently, IC1b's output must now ramp linearly in a *positive* direction to maintain  $V_-$  equal to  $V_+$ .

When  $V_{OUT(TRI)}$  crosses the Schmitt's upper threshold, IC1a's output,  $V_{OUT(SQ)}$ , goes back into positive saturation, and the process repeats. The resulting waveform at IC1b's output is a triangle wave which ramps between the Schmitt's threshold levels, i.e., the amplitude of  $V_{OUT(TRI)}$  equals the hysteresis voltage,  $V_H$ .

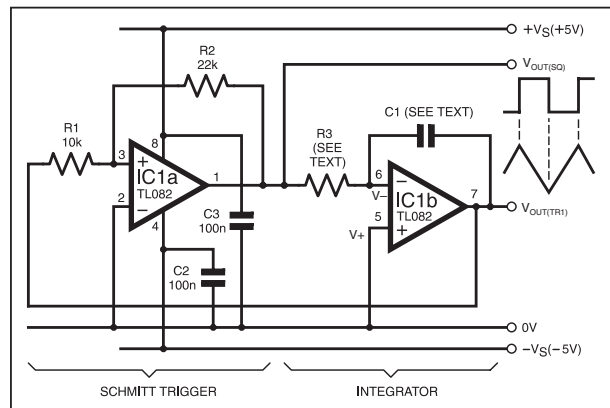


Fig.4.8. Circuit diagram combining a Schmitt trigger and integrator to form a Function Generator.

## AMPLITUDE AND FREQUENCY

Since the hysteresis  $V_H$  is set by resistors R1 and R2, the magnitude of  $V_{OUT(TRI)}$  can be controlled by varying the ratio of these resistors. The time constant  $\tau$  equals  $(C1 \times R3)$  which, together with  $V_H$ , determines the pulse widths and frequency of operation:

$$T1 = \tau \times \left\{ \frac{V_H}{V_{SAT+}} \right\} \text{ (s); } T2 = \tau \times \left\{ \frac{V_H}{-V_{SAT-}} \right\} \text{ (s);}$$

$$\text{and Frequency } f = \frac{(V_{SAT+}) \times (-V_{SAT-})}{V_H \times (V_{SAT+} - V_{SAT-}) \times \tau} \text{ (Hz)}$$

If  $V_H$ ,  $V_{SAT+}$  and  $V_{SAT-}$  are held constant, the frequency can be continually adjusted by making R3 a variable resistor, and can be varied in decade steps by switching in different values of C1.

With  $R3 = 20k\Omega$  and  $C1 = 1nF$ , the waveforms produced using a TL082 dual op.amp are shown in Fig.4.9. The TL082 has very low input bias current and is specified for operation with supplies up to  $\pm 15V$ . Although reasonably fast, it is not a rail-to-rail device; this can be seen in Fig.4.9, where  $V_{OUT(SQ)}$  swings between  $-3.6V$  and  $+4.2V$ , resulting in a slight asymmetry in the triangle wave timing. Notice how linear the triangle wave is: compare it with the "exponential" waveform shown in Fig.4.3.

When operating on  $\pm 5V$  supply rails, the TL082 produces a well-shaped triangle wave at frequencies up to 60kHz. At higher frequencies, the triangle peaks start to look "rounded" and the square wave edges become "sloped" due to slow rate limitations.

## ZERO-CROSSING DETECTOR

In the circuits we have examined so far, the Schmitt trigger has been used in a "self-contained" fashion to generate an output waveform. However, some of the most useful applications for the Schmitt exploit its ability to convert an analogue signal (often slowly changing or poorly shaped) into a digital signal with well-defined amplitude and rapid transition times.

In this capacity, the Schmitt forms an ideal *interface* between sensors and digital systems, two examples of which will be described shortly. First, though, we shall see how the Schmitt is used as a *zero-crossing detector*.

In certain applications, particularly in commercial and industrial power systems, it is necessary to detect when the sinusoidal mains voltage waveform crosses through zero. This "zero-crossing" point can be used to trigger power devices such as thyristors, where it is useful in minimising the electromagnetic interference generated when the devices switch on and off.

There are many ways of detecting the mains zero-crossing point; the circuit in Fig.4.10a is just one incarnation of a zero-crossing

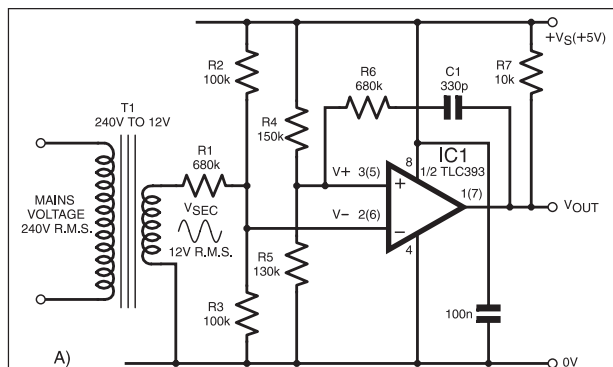


Fig.4.10a. Circuit diagram for a Zero-Crossing Detector using a transformer and an inverting Schmitt trigger.

Fig.4.10b (right). circuit waveforms for the Zero-Crossing Detector.

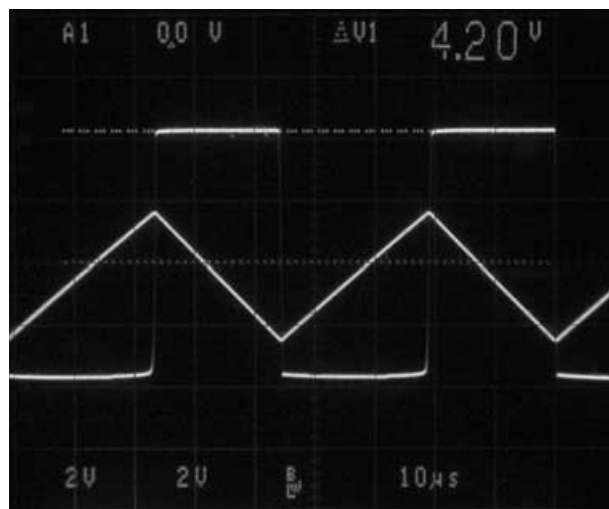
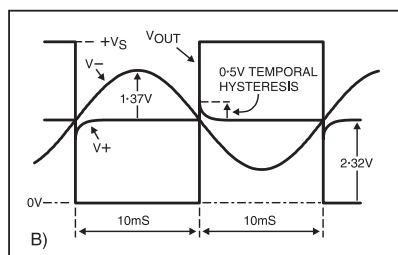


Fig.4.9. Function Generator Waveforms. Pulse waveform is  $V_{OUT(SQ)}$  (2V/div.). Triangular waveform is  $V_{OUT(TRI)}$  (2V/div.). Timebase: 10μs/div.

detector which uses a transformer, T1, to provide a mains reference signal. In practice, the circuit would probably be arranged differently to allow transformer T1 to provide power to a load. However, as it stands, the circuit can easily be breadboarded for experimental purposes, and provides a good example of *temporal* hysteresis which was introduced in Part Two.

## TRANSFORMER SECONDARY VOLTAGE

Transformer T1 in Fig.4.10a has a root mean square (r.m.s.) secondary voltage of  $V_{SEC(RMS)}$  of 12V (transformers with different secondary voltages could be used with appropriate circuit modifications). Therefore, the *peak* secondary voltage is  $V_{SEC(PEAK)} = \pm \sqrt{2} \times 12V$ , or  $\pm 17V$ . Since T1 is effectively "off load", we must assume that  $V_{PEAK}$  could be a maximum of  $\pm 20V$ .

Since comparator IC1 is powered by a single +5V rail, resistors R1, R2 and R3 must be selected to ensure the voltage,  $V_-$ , at the comparator's inverting input remains within its common mode range, which for the TLC393 is 0V to +4V. Using the *superposition theorem*, the voltage at the inverting input can be found:

Inverting Input Voltage,

$$V_- = \frac{V_{SEC} \times (R2//R3)}{R1 + (R2//R3)} + \frac{(+V_S) \times (R1//R3)}{R2 + (R1//R3)} \text{ (volts)}$$

where // means "in parallel with".

Clearly, since  $+V_S$  is positive,  $V_-$  will be a maximum when  $V_{SEC}$  is at its maximum positive value, namely +20V. With  $R1 = 680k\Omega$ ,  $R2 = 100k\Omega$ , and  $R3 = 100k\Omega$ , we find that:

$$\begin{aligned} V_-(\text{max}) &= \frac{20 \times (100k\Omega//100k\Omega)}{680k\Omega + (100k\Omega//100k\Omega)} + \frac{5 \times (680k\Omega//100k\Omega)}{100k\Omega + (680k\Omega//100k\Omega)} \\ &= 1.37 + 2.33 = 3.7V \end{aligned}$$

Therefore, provided  $V_{SEC(PEAK)}$  does not exceed 20V and  $+V_S$  is regulated to +5V,  $V_-$  will remain within the 0V to 4V common mode input voltage range.

Now, we require the comparator to trip each time the mains sinusoid crosses the zero point. Provided T1's primary and secondary voltages are in phase, this will coincide with the secondary voltage crossing zero, i.e., when  $V_{SEC} = 0$ . Substituting this value in the expression for  $V_-$ , we see that:

$$\begin{aligned} V_- \text{ at zero-crossing point} &= 0 + \frac{5 \times (680k\Omega//100k\Omega)}{100k\Omega + (680k\Omega//100k\Omega)} \\ &= 0 + 2.33 = 2.33V. \end{aligned}$$

Therefore, by selecting resistors R4 and R5 to make the non-inverting input voltage,  $V_+$ , equal to 2.33V also, the comparator will trip each time the mains signal crosses zero. With  $R4 = 150k\Omega$  and  $R5 = 130k\Omega$ , the quiescent value of  $V_+$  is 2.32V.

Resistor R6 and capacitor C1 provide around 0.5V of temporal hysteresis; this decays to zero after about 1ms as shown by the circuit waveform diagram in Fig.4.10b. The amount of this "transient" hysteresis can be increased by reducing R6 and/or increasing C1 if there is excessive noise on  $V_{SEC}$ .



## PULL-UP RESISTOR

The TLC393 is a low-power, dual comparator with open drain output, therefore a pull-up resistor, R7, is needed at the output. Resistor R7 can be omitted if a comparator like the TLC3702 having rail-to-rail output swing is used.

Both the TLC393 and TLC3702 have very low input bias currents (typically just 5pA) so large resistance values can be used for R1 to R6. If an alternative device such as the LM393 is used, beware that the bias currents are much larger (250nA maximum), so it may be necessary to scale down the resistor values.

Tests on the Zero-Crossing Detector circuit of Fig.4.10a revealed that the timing error (the time difference between the zero-crossing points and the rising or falling edge of  $V_{OUT}$ ) was less than 65µs, which is just 0.33% of the 20ms mains period.

**Finally, a word of caution. When experimenting with zero-crossing detectors, never be tempted to connect the Schmitt trigger circuitry directly to the mains supply. Not only is this likely to destroy the low voltage components, but it also bypasses the galvanic isolation provided by the transformer, a practice which can be fatal.**

## TEMPERATURE DETECTOR

Temperature is probably the most commonly measured physical parameter, so it is not surprising that it can be measured with many different types of sensor, such as thermocouples, RTDs (resistance temperature detectors), thermistors, and so on.

The humble bipolar junction transistor (BJT) makes a surprisingly good temperature sensor. For most silicon devices, the base-emitter junction exhibits a reasonably linear temperature coefficient of around  $-2\text{mV}/^\circ\text{C}$ . How an *npn* transistor can be combined with an amplifier and Schmitt trigger to produce an inexpensive temperature detector is shown in Fig.4.11.

Transistor TR1 is the sensor. It is “diode-connected” (its base and collector are connected together), and is biased by resistor R1 which produces a nominal collector current,  $I_C$ , of around  $100\mu\text{A}$ . Provided the supply voltage,  $+V_S$ , is held constant, the only changes in base-emitter voltage,  $V_{BE}$ , will be due to changes in TR1’s ambient temperature.

Almost any low-power, small-signal, *npn* silicon transistor could be used, but the 2N3904 is well-suited to temperature measurement and is widely used for temperature sensing applications. The combination of resistor R2 and capacitor C1 form a low-pass filter which helps to remove any mains pickup or other low-frequency noise which gets onto the sensor. (If TR1 is located some distance from IC1a, it should be connected to the circuit via a “twisted pair” of wires to minimise pickup on the wires themselves).

Op.amp IC1a should have a wide output swing to accommodate as much gain as possible. With resistor R3 selected at  $120\text{k}\Omega$  and R4 at  $30\text{k}\Omega$ , the amplifier has a gain of five, such that  $V_A = 5 \times (V_{BE} + \Delta V_{BE})$ , where  $V_{BE}$  is the quiescent, room temperature base-emitter voltage, and  $\Delta V_{BE}$  is the change in  $V_{BE}$  caused by temperature variations.

## THRESHOLD LEVELS

Op.amp IC1b acts as a comparator and forms the Schmitt trigger, with hysteresis set by resistors R7 and R8; trimmer pot VR1 provides a variable reference voltage,  $V_{REF}$ , at the inverting input which is used to calibrate the detector. The circuit values have been chosen such that the Schmitt’s thresholds correspond to temperature levels of approximately  $+25^\circ\text{C}$  and  $+35^\circ\text{C}$ , although it could be adapted to trip at other temperatures if required.

Assuming TR1’s temperature coefficient is  $-2\text{mV}/^\circ\text{C}$ , an increase in temperature of  $10^\circ\text{C}$  will cause a change in  $V_{BE}$  of:  $\Delta V_{BE} = 10^\circ\text{C} \times (-2\text{mV}/^\circ\text{C}) = -20\text{mV}$ . The corresponding change in  $V_A$  will be:  $\Delta V_A = 5 \times \Delta V_{BE} = 5 \times -20\text{mV} = -100\text{mV}$ . Therefore, the Schmitt trigger’s hysteresis must be set to  $100\text{mV}$ ; provided  $V_{OUT}$  swings from  $0\text{V}$  to  $+5\text{V}$ , this is accomplished by selecting R7 =  $2\text{k}\Omega$  and R8 =  $100\text{k}\Omega$ .

The values chosen for R5, VR1 and R6 provide a  $V_{REF}$  range of around  $2.60\text{V}$  to  $3.20\text{V}$ . This allows the circuit to be calibrated to accept any value of  $V_{BE}$  at  $25^\circ\text{C}$  from  $540\text{mV}$  to  $640\text{mV}$ . The way

this relates to the circuit’s behaviour can be understood by following the calibration routine.

## CALIBRATING THE DETECTOR

Assuming the particular sample of transistor TR1 in Fig.4.11 has a room temperature ( $+25^\circ\text{C}$ ) value of  $V_{BE} = 580\text{mV}$ , such that  $V_A = 5 \times 580\text{mV} = 2.9\text{V}$ . Starting with  $V_{REF}$  at its maximum value such that  $V_{OUT}$  is low and the l.e.d. D1 is on, preset VR1 is carefully adjusted until  $V_{REF}$  is just slightly less than  $V_A$ , at which point the comparator trips,  $V_{OUT}$  goes high and the l.e.d. turns off.

If the temperature now increases slightly, the comparator does not trip – the hysteresis prevents it from doing so. However, when the temperature increases to  $+35^\circ\text{C}$ , the value of  $V_A$  will be low enough to take IC1b’s non-inverting input voltage below  $V_{REF}$ : the comparator trips,  $V_{OUT}$  goes low and l.e.d. D1 turns on, signaling that the upper temperature threshold has been reached. Whilst  $V_{OUT}$  remains low, the l.e.d. stays on until TR1’s temperature has fallen back down to  $+25^\circ\text{C}$ , at which point the comparator trips again and D1 turns off.

When calibrating the detector, the simplest way to raise TR1’s temperature is to apply heat from a soldering iron; it can quickly be cooled down again using “freezer spray”, or by touching it with a suitable object (e.g. a screwdriver) which has been left in the freezer for an hour or so!

The circuit’s accuracy depends largely on the “quality” of its calibration. *Repeatability* (the degree to which the circuit trips at the same threshold levels over a period of time) depends mainly on the stability of the hysteresis levels, which in turn depend on  $V_{OUT}$  and  $+V_S$ .

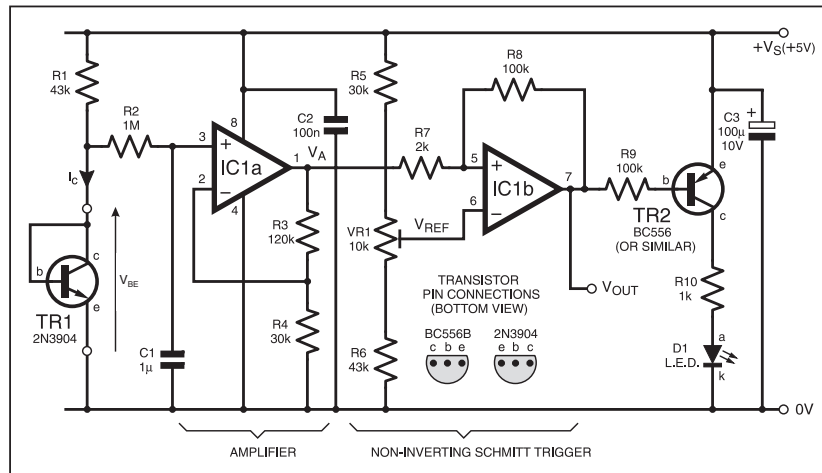


Fig.4.11. Circuit diagram for a transistor-based Temperature Detector.

## TRIPPING THE LIGHT FANTASTIC

Like temperature, light is also a commonly measured quantity, and can be sensed using devices like photodiodes, phototransistors and light dependent resistors (l.d.r.s). Usually made from Cadmium Sulphide (CdS), the l.d.r. is strictly a *photoconductive cell* in which the conductivity increases in logarithmic fashion as the light intensity increases.

Light dependent resistors are relatively cheap and make ideal sensors for threshold-type light detectors. An example circuit diagram for a Light Detector with an audio output is shown in Fig.4.12. The l.d.r. sensor (R2) is connected, together with VR1 and R1, in a potential divider network at the input to an inverting Schmitt trigger formed by comparator IC1a. A second comparator, IC1b, is configured as a “gated” astable which drives the piezoelectric sounder WD1.

Preset potentiometer VR1 is used to set the trigger threshold. The values chosen for R1 and VR1 depend on the particular light level that must trip the comparator. For instance, if the circuit is required to detect a range of relatively high light intensities, then resistor R1 and preset VR1 must be small; on the other hand, operation in dull conditions will require higher resistance values.

Tests on three samples of the NORP12 revealed that in bright sunlight the sensor resistance ranged from 40 to 50 ohms. In relatively dark conditions, however, the sensors’ resistance was in the hundreds of kilohms range.

Few of us are likely to possess a calibrated light source, so the easiest way to experiment with this circuit is to place the l.d.r. sensor at varying distances from a mains-powered, filament-type 60W

light bulb in an otherwise darkened room. Changing the distance between sensor and bulb effectively varies the light intensity falling on the sensor.

For example, at just 3cm from the bulb, the sensor resistance was measured as  $104\Omega$ ; with the distance increased to 30cm the resistance increased to  $552\Omega$ . (Interestingly, the relationship between distance and resistance is fairly linear, suggesting the l.d.r. could be used in conjunction with a light source as a crude "distance meter" – albeit only in the dark!)

### MID-HYSTERESIS POINT

With resistors R3 and R4 both equal to  $10k\Omega$ , and provided IC1a has a rail-to-rail output swing, the mid-hysteresis point of the Schmitt trigger will be  $+V_S/2$ , or 2.5V. Therefore, if preset VR1 is adjusted such that  $R1+VR1$  equals the sensor resistance at the required light level, then the voltage,  $V_{SENSE}$ , on l.d.r. R2 will also equal 2.5V and the comparator will trip.

In this circuit (Fig.4.12), resistor R5 must be selected to provide adequate hysteresis. The degree of hysteresis required will depend on the operating conditions. One reason for requiring hysteresis is to eliminate the effects of background light fluctuations which could otherwise cause the detector to "oscillate" about the trip point.

However, a more important reason for requiring hysteresis in this kind of experimental set-up is to suppress the effects of mains "ripple" in the light bulb intensity. With the values of  $R1+VR1$  set to  $470\Omega$ , and with the sensor (R2) located 3cm from the 60W bulb, the r.m.s. component of  $V_{SENSE}$  was measured as 25mV. This a.c. component is caused by the 50Hz mains voltage which effectively "modulates" the light intensity at 100Hz and acts as a kind of "noise". (Why is the modulation frequency *twice* the mains frequency?)

An r.m.s. voltage of 25mV corresponds to a *peak-to-peak* ripple voltage of 71mV. Therefore, resistor R5 must be selected to provide hysteresis of at least 71mV such that the ripple voltage on  $V_{SENSE}$  does not upset the trip point. With  $R5 = 240k\Omega$ , the thresholds are  $V_{TL} = 2.449V$  and  $V_{TH} = 2.551V$  and the hysteresis is  $V_H = 102mV$ . Reducing R5 will increase the hysteresis if more "noise immunity" is required.

### GATED OSCILLATOR

When the light intensity is low, the l.d.r. sensor's resistance is large compared to  $R1+VR1$ , and so  $V_{SENSE}$  is greater than 2.5V, causing IC1a's output to be in negative saturation. Since the TLC3702 dual comparator is capable of rail-to-rail output swings, diode D1's cathode (k) potential will be very near to 0V.

Consequently, D1 is forward biased, effectively "clamping" the voltage on capacitor C2 to around 0.7V. This prevents the astable from oscillating, and forces IC1b's output voltage into positive saturation such that there is no voltage across the piezoelectric sounder WD1.

However, as the l.d.r. sensor (R2) is moved *closer* to the light source, its resistance falls and  $V_{SENSE}$  decreases. When the sensor resistance is low enough, the detector trips and IC1a's output goes

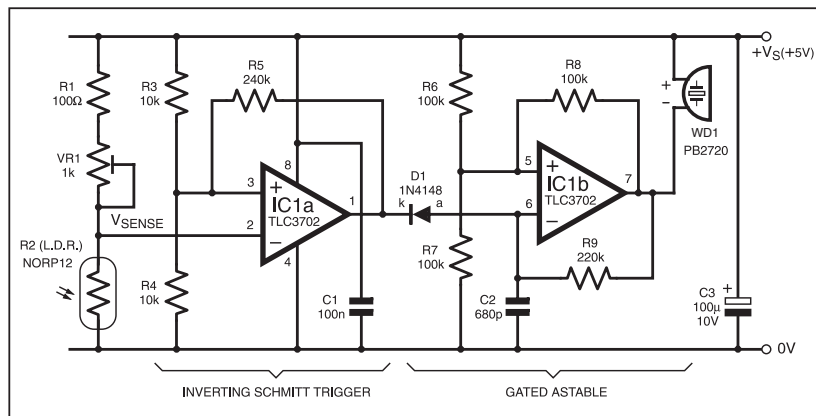


Fig.4.12. Circuit diagram for a Light Detector, with audible output.

high, reverse biasing diode D1. The astable is now free to run, and the squarewave voltage at IC1b's output causes WD1 to sound.

### RESONANT FREQUENCY

Capacitor C2 and resistor R9 set the astable's time constant. This should be chosen to set the operating frequency as close as possible to the piezoelectric sounder's resonant frequency. With the component values shown in Fig.4.12, the frequency is around 4-4kHz, quite close to WD1's resonant frequency of 4.5kHz. If alternative sounders are used, C2 and R8 should be adjusted, if necessary, to suit the sounder's characteristics.

Calibrating the Detector stage is easy. Start with preset VR1 at its minimum resistance and locate the l.d.r. sensor R2 at the required distance from the light bulb. Then, slowly adjust VR1 until sounder WD1 just begins to sound.

As the sensor is moved either side of the threshold point (the preset distance from the bulb), the sounder should turn on and off "cleanly". However, if resistor R5 is removed from the circuit, such that the comparator no longer has any hysteresis, the sounder will now produce a "squawking" sound when the sensor is moved near the trip point: this is caused by the mains ripple effectively modulating the astable's output frequency.

This dramatic effect is a perfect example of how hysteresis can be used to overcome the problems caused by noise and interference. In this case, the unwanted signal is the ripple voltage on  $V_{SENSE}$ . It oscillates at twice the mains frequency simply because the mains sinusoid reaches a peak (one positive, one negative) *twice* each cycle: each peak in the mains voltage causes a slight increase in the bulb's light output, i.e., the light intensity is "modulated" at twice the 50Hz mains frequency.

### LOOKING AHEAD

The Light Detector circuit in Fig.4.12 employs not one, but two Schmitt triggers, each performing a different task. There can be little doubt that the Schmitt function is a versatile and essential element in analogue systems built using op.amps and comparators. However, as we shall see in Part Five, the Schmitt trigger finds many applications in digital systems, where specialised Schmitt trigger logic gates are available to simplify the design task.

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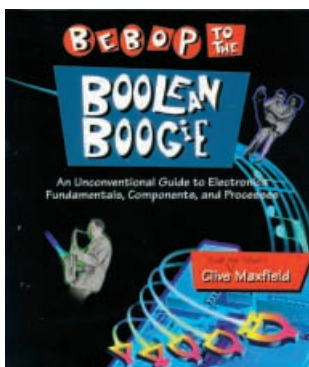
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boards are fabricated, and what the innards of memory ICs look like. You'll also gain a working knowledge of Boolean Algebra and Karnaugh Maps, and understand what Reed-Muller logic is and how it's used. And there's much, MUCH more (including a recipe for a truly great seafood gumbo!).

Hundreds of carefully drawn illustrations clearly show the important points of each topic. The author's tongue-in-cheek British humor makes it a delight to read, but this is a REAL technical book, extremely detailed and accurate. A great reference for your own shelf, and also an ideal gift for a friend or family member who wants to understand what it is you do all day. . . .

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## Bebop Bytes Back

By Clive "Max" Maxfield and Alvin Brown

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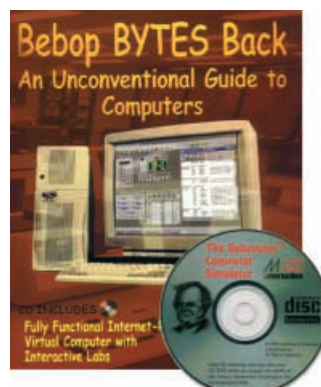
"1. The more time you spend with this book and its accompanying CD-ROM, the more you'll get out of it. Skimming through it won't take you where you want to go. Paying serious attention, on the other hand, will teach you more about computers than you can imagine. (You might also see a few beautiful sunrises.)

2. The labs work on two levels: on and under the surface. When you're performing the labs you'll need to look for patterns that build up from individual events.

3. When you're done, you won't look any different. You won't get a trophy or a certificate to hang on your wall. You'll have some knowledge, and some skill, and you'll be ready to find more knowledge and develop more skill. Much of this will be recognisable only to someone who has the same knowledge and skill."

This follow-on to *Bebop to the Boolean Boogie* is a multimedia extravaganza of information about how computers work. It picks up where "Bebop I" left off, guiding you through the fascinating world of computer design . . . and you'll have a few chuckles, if not belly laughs, along the way. In addition to over 200 megabytes of mega-cool multimedia, the accompanying CD-ROM (for Windows 95 machines only) contains a virtual microcomputer, simulating the motherboard and standard computer peripherals in an extremely realistic manner. In addition to a wealth of technical information, myriad nuggets of trivia, and hundreds of carefully drawn illustrations, the book contains a set of lab experiments for the virtual microcomputer that let you recreate the experiences of early computer pioneers.

If you're the slightest bit interested in the inner workings of computers, then don't dare to miss this one!



## Audio and Music

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The PIC processors have plenty of useful features, but they are still reasonably simple and straightforward to use. This book should contain everything you need to know.

Topics covered include: the PIC register set; numbering systems; bitwise operations and rotation; the PIC instruction set; using interrupts; using the analogue to digital converter; clock circuits; using the real time clock counter (RTCC); using subroutines; driving seven segment displays.

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Various circuits using inductors and capacitors are covered, with emphasis on stable low frequency generation. Some of these are amazingly simple, but are still very useful signal sources.

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**R. A. Penfold**

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The topics covered in this book include: the basic concepts of logic circuits; the functions of gates, inverters and other logic "building blocks"; CMOS logic i.c. characteristics, and their advantages in practical circuit design; oscillators and monostables (timers); flip/flops, binary dividers and binary counters; decade counters and display drivers.

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**(Second Edition) Ian Sinclair**

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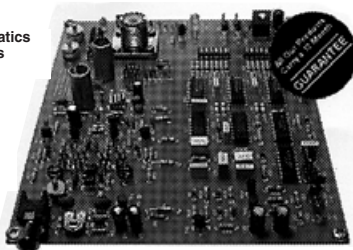
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Published on approximately the second Thursday of each month by Wimborne Publishing Ltd., Allen House, East Borough, Wimborne, Dorset BH21 1PF. Printed in England by Apple Web Offset Ltd., Warrington, WA1 4RW. Distributed by COMAG Magazine Marketing, Tavistock Rd., West Drayton, UB7 7QE. **Subscriptions** INLAND: £14.50 (6 months); £27.50 (12 months); £50 (2 years). OVERSEAS: Standard air service, £17.50 (6 months); £33.50 (12 months); £62 (2 years). Express airmail, £27 (6 months); £51 (12 months); £97 (2 years). Payments payable to "Everyday Practical Electronics", Subs Dept, Allen House, East Borough, Wimborne, Dorset BH21 1PF. E-mail: [subs@epemag.wimborne.co.uk](mailto:subs@epemag.wimborne.co.uk). EVERYDAY PRACTICAL ELECTRONICS is sold subject to the following conditions, namely that it shall not, without the written consent of the Publishers first having been given, be lent, resold, hired out or otherwise disposed of by way of Trade at more than the recommended selling price shown on the cover, and that it shall not be lent, resold, hired out or otherwise disposed of in a mutilated condition or in any unauthorised cover by way of Trade or affixed to or as part of any publication or advertising, literary or pictorial matter whatsoever.